THE SOILS THAT SUPPORT US

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THE MACMILLAN COMPANY
NEW YORK · CHICAGO
DALLAS · ATLANTA · SAN FRANCISCO
LONDON · MANILA
IN CANADA
BRETT-MACMILLAN LTD.
GALT, ONTARIO

THE SOILS THAT SUPPORT US

An introduction
to the study of soils
and their use
by men

CHARLES E. KELLOGG

New York

The Macmillan Company

1959

Set up and electrotyped. Published August, 1941.

Eleventh Printing 1959

: Printed in the United States of America :

TO

L. R. SCHOENMANN

Who First Showed Me the Soil

Between the soil of the country and the intelligence of men, there have always been close analogies which we find are logical and necessary as soon as we understand that the mind invents nothing—discovers everything.—Elie Faure, *History of Art.*

PREFACE

THIS book is about soil, and how soil and people get on together. Rather it should be soils, since there are many kinds, just as there are many kinds of people. Both soils and people have their own peculiarities. Indeed, one of the major problems of existence has been and always will be the relationship of different people to these individual soils. Then, as there are races of people, there are great soil groups with differences of vast importance, not only to the farmer and the forester, but to every one of us.

Each soil has had its own history. Like a river, a mountain, a forest, or any natural thing, its present condition is due to the influences of many things and events of the past. No one of these is entirely responsible for it. Indeed, one cannot see the effect of any single one. Rather, what one sees is the result of many forces acting together, and the effect of each is merged with the effect of the others. Always there is change—perhaps a tiny bit, perhaps a great deal. A soil that we see today may be better or poorer, or just different, than the one we saw yesterday in the same place. Thus the soils that support us are the products of different combinations of rock, climate, slope, vegetation, and time. Even the good soils are vastly different. A good soil for rubber trees is not the same as a good soil for wheat; and one good for clover is quite un-

like one good for strawberries. Nature has had to make many right combinations to produce all the various kinds of good soil in the world.

Beyond the forces that produce the natural soils are the influences of man when he cultivates these different soils or grazes his herds upon them, using them for his own ends. Good soils may be made even better by proper use; or they may be made poorer through carelessness or abuse. Such abuse may or may not be the fault of the individual cultivator or forester—more often it is due to a failure of laws and public policies as they apply in different soil areas. On the other hand, poor soils have often been made very good through careful management; other times they have been made still poorer.

Science offers man a better opportunity than he has ever had before during his long history to make his future secure. On the other hand, scientific techniques can be used to exploit the men who cultivate, and the soil that supports them, on an even grander scale. Somehow the choice will be made, consciously or unconsciously.

Each soil is made up of mineral and organic materials arranged in ways peculiar to itself. Each is productive for certain plants. Each responds in its own way to different treatments. And, above all, each offers certain possibilities for people to establish secure homes and satisfying ways of living. The bond of relationship between man and soil is so deep and so fundamental that there is great danger of superficial recognition of a few symptoms and the application of superficial remedies that may even hasten the process of degradation. To all people, whether they gain their living directly from the soil or not, it is important to know that these things are so and to think deeply upon what our own course, as a people, should be.

Nature has endowed the earth with glorious wonders and vast resources that man may use for his own ends. Regardless of our tastes or our way of living, there are none that present more variations to tax our imagination than the soil, and certainly none so important to our ancestors, to ourselves, and to our children.

Those who have an interest in things that live in the woods or on the open range, in the field or in the garden, are led to study the soil and appreciate its many variations and possibilities. But beyond its interest as natural history, the soil lies at the very foundation of our existence as cultural beings.

Few of the ideas in this book are original with the author. Since his work has taken him into most parts of his own country, and others as well, there has been opportunity to talk with different kinds of people living on many kinds of soil. Some of the ideas have come from books, others were suggested by the questions of students, and many came from the letters and conversations of farmers. Part of these ideas and the results of the author's own researches have already been presented separately and in more detail. Most of the photographs and drawings were made by the author in connection with his work in the North Dakota Agricultural College, in the University of Wisconsin, and especially in the United States Department of Agriculture. Some were gratefully received from his associates. To those who made these travels and researches possible, and to those who have patiently explained their ideas, the author will be eternally grateful.

Some of these ideas about soils and how people live with them seem so fundamental to a continuity of our way of life that the author has tried to bring them together,

simply, in one place. It is hoped that those who wish to see a little more of the world in which we live and to sharpen their view of our future possibilities may find something in these pages.

Here and there the author has ventured a little way out of his own special field in trying to show a few of the relationships of soils and their use to other things that people use and think about. In these other fields he is a humble layman, and hopes for tolerance from those who really understand them, in exchange for humility. Very many alluring side paths branch off from the main theme, but none can be explored very far—not in one little book.

Although the reader may find a few new terms, technical discussions and words have been avoided in order to deal with the main principles simply. Since the significance of each part of the soil depends upon the other parts, and since each kind of soil is related to other kinds, it is suggested that the reader glance through the whole book hurriedly in advance, looking at the pictures, diagrams, and maps. Some may even want to read the later chapters before reading the foundation material in the first few chapters carefully. While reading, an occasional glance at the map to see where specific soil groups are located, at the large table in the second appendix in which all the groups are briefly described, and at the glossary for unfamiliar words, may be helpful.

Charles E. Kellogg

Arlington, Virginia

June, 1941

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THE SOILS THAT SUPPORT US

1.

IN THE FIRST PLACE

IN THE first place, there are two things necessary to science—facts and ideas. Simple facts or observations can only be useful to us if there are some connecting ideas; and ideas must be illustrated and supported by facts, or else they may lead us in the wrong way. Sometimes we complain that the man who is all idea doesn't get things done—that it is the practical man who really goes places. But unless the man who does things has correct ideas as well as facts, we will find that he has gone, to be sure, but to the wrong place. Thus ideas without facts or facts without ideas accomplish nothing.

Not only must we have facts and ideas, but our facts must be plentiful, else our ideas will be too narrow. For example, it may be a fact that this house and the one across the road are white. But we must examine others before concluding that all houses are white. This danger of oversimplification is very great in soil science. There are so many kinds of soil in the world that even those who devote their lives to the study of soils cannot hope to see all of them, and most people really become acquainted with only a very few, if any. Thus the facts that people have may be so limited that the conclusions they draw from them can be true only for a small area. As applied to other regions their ideas may be ever so wrong.

People have been gathering facts and forming ideas

since earliest time. Very few great forward steps have been made at one time in any science. Rather, progress is made through the combined effort of many people working for a long time. Great scientists appear from time to time, but sometimes we are inclined to give them too much credit, forgetting the hundreds of others who may not have been quite so well known, for one reason or another, but whose work was an essential part of the whole. Or again the inspiration of an obscure teacher may have its effect by getting others to work and think.

The overthrow of one scientific idea by another is not really an overthrow at all. One gets an idea from the facts at hand. When more facts are had, the idea must be changed to fit all the facts. Thus one idea follows another as our knowledge grows. Certainly this has been true of our ideas about the soil. Once it was veiled in mystery, something containing unknown vital stuff that gave life; then it became a simple storage bin; now it is thought of as a complex natural body, no more, no less mysterious than the plants and animals that live in it and on it.

For science to be useful there must be more than facts about things and relationships between things. Even though soil science made great progress in the study of just soils, that would not be enough. People use these soils. They have blessed them and cursed them, sweated over them and loved them, lived from them and died for them. The soil is absorbed into the life of the farmer. Races have their roots in them. In the application of his science, the scientist is dealing also with the relationships of facts to men. His researches, his quests for information, must be partly shaped by these relationships.

A farm, or a village or community of farmers, is a social

unit, a group of people. Even though they work the soil and live on it, they have many other hopes and aspirations besides the desire for large yields and secure soil resources. It is within this broader social framework that the principles of soil science must find their application, along with other principles. Sometimes there are conflicts. The soil scientist should not become impatient if he must compromise the ideal plan for the soil with other plans. After all, it is easy to imagine a farm or a community, or even a nation, where the soil might be handled perfectly according to the chilly principles of a "pure" soil science and, at the same time, be a colorless, miserable, hopeless place in which to live and raise a family.

Although in his researches the scientist must be calm and objective, in the application of the principles he formulates from his results, the people are as important as the soil. At the same time the scientist must be no less a scientist but rather more of an artist. There can be no choice between strictly objective science without broad understanding of people on the one hand, and great human sympathy without clear understanding of the facts, on the other. The one leads to a drab mechanical existence, the other to careless sentimentalism.

Scientists in early times gave little attention to the soil. Like other things of everyday life, it was not thought to be a fit subject for study. The early Greek scientists, or natural philosophers, looked down upon agriculture as one of the crude arts. They studied the stars and geometry. Rarely did they dig into the soil or make experiments with plants. Such work would have been beneath their dignity; agriculture was for the slaves. Even today a few people may have this feeling. To them, somehow a student of soils is not quite so learned as one who studies

the broken atoms or traces the chilly paths of the stars. Certainly soils are not less interesting, even if their study leads finally to some practical improvement in agriculture or forestry.

For many centuries knowledge of soils and agriculture was almost entirely in the hands of the simple folk—the people on the land. They passed their knowledge, their facts and their ideas, from one generation to the next, each probably adding a tiny bit. By the time of Julius Caesar there was a great deal known—not from experiments or careful scientific study but from the long, painful experience of people struggling for years and years on the same soil, finally learning how to master it. But ideas about soils were confusing because the experience of the Roman farmer would be quite unlike that of the Egyptian farmer. We know now that the soils of Italy are quite different from those along the Nile River, each year overflowing its banks.

About this time men began to gather their knowledge together. A few (too few) Romans began to see that if the great Roman Empire were to last their agriculture must thrive. These men tried to get their countrymen to see the need for more careful treatment of their farms so that Rome might continue to have strong country folk at home. But apparently it was too late. Roman farms had become country estates, worked by slaves who had little interest in the land, and owned by city dwellers who rarely saw them except to collect the rents. Even this might be done by paid agents. About A.D. 50 Columella compiled his great book on *Husbandry*, probably the greatest book on agriculture ever written in any language. During the long period after the fall of Rome and before science again began to occupy men's minds

this book remained the highest authority on agricultural affairs. There is a great deal in it about soils, about different kinds of soils, what they can be expected to produce, and how they should be managed for best results. Of course, many of the author's facts and ideas could be applied only to soils similar to those in the Italian peninsula.

Following the period of the Greeks and Romans, men began the search for the philosopher's stone—some mysterious substance that might turn lead into gold. What made living matter different from dead things? How could the young plant grow? It was thought that some mysterious substance in the soil—some one particular substance—must be responsible for this "spirit of vegetation." When wood or other plant remains are burned there is left an ash or salt. Some people noticed this and reasoned that the salt was the spirit of vegetation. Others saw, however, that water was useful to plants. In fact a famous Dutch scientist, Von Helmont, grew a willow tree for five years in soil to which he had added nothing but rain water. It grew lustily and gained a great deal of weight. He had carefully weighed the dry soil at the beginning and at the end of the experiment. The soil had lost only 2 ounces—within the error of his experiment—so he concluded that water was the thing—the spirit of vegetation.

Later, an English scientist, Woodward, reasoned that if water were the "spirit," then plants should grow in pure water. This he tried, growing peas in rain water, in water from the Thames River, and in that from a mud hole in his garden. The peas grew scarcely at all in rain water, only indifferently in the river water, but lustily in the water from the mud hole. Certainly he said, the only

difference among these waters is the amount of fine earth in them. That is the spirit of vegetation.

And so things went as long as the search was for a spirit—for some one panacea, or single cause. Now we know that many things are necessary for the growth of a plant—one cannot say that one is more important than the others. With the great growth of science just before and following the French Revolution, the attention of scientists in western Europe was directed toward soil fertility. The population was increasing rapidly—more rapidly than the food supply. Many had too little food and the scientists were especially anxious to find ways of increasing the yields of food crops. Chemists began to make analyses of crop plants and found that they took certain things from the soil. Later, by growing plants in water or in clean sand it was proved that many chemical elements were needed by plants for growth. Some were needed only in very small amounts—but nevertheless they were necessary. This can be shown easily by growing plants in water or sand that contains all of the necessary elements but one. Of course, these early workers soon found that the great bulk of a plant is made up of organic compounds—compounds produced in the plant itself—rather than inorganic salts. When a plant is burned, as wood in the fireplace, only a little remains as ash or salt. The rest is composed mostly of elements taken from the air and water, not from the soil.

Thus, it was thought that if plants need certain elements from the soil, and one keeps growing plants on the same soil year after year, these elements would be all used up, and the soil would become infertile or "exhausted." Of course, under natural conditions this wouldn't happen, because the plants would die, fall down,

rot, and return the elements back to the soil again. For arable soils, that is, soils plowed and used for crops, if one analyzed a soil and found how much of these various elements there were in it and if one knew the amount of each that a crop needed, a sort of balance sheet could be made. The soil was looked upon as a sort of storage bin of plant nutrients—or a sort of bank. Starting with a given amount of money (plant nutrients) in the bank (soil) and by writing checks (growing crops) the money would soon be gone, unless more money was put back into the bank (as fertilizer in a soil). At first this idea seemed so reasonable that it was widely accepted.

It was a good idea and helped to explain a lot. But there were many things that it did not explain. It didn't explain why soils were so different in the first place—some very poor and others very rich. At first this was thought to be because the soils came from different rocks, and these rocks had different amounts of the chemical elements in them. It is true that in a small area, like a single county in the United States, where there are only very small differences in climate or in the native plants, differences in soils will follow differences in rocks. But as soon as we go over a large area—a continent—we will find all kinds of soils, rich and poor, developed from the same rocks.

Then again one could point to lands in Europe itself that had been farmed for many centuries, like many of those along the Danube River, and were as fertile as ever—indeed yields had increased rather than become smaller. There were other difficulties. Some plants might contain a lot of some one element, but fertilizers containing that element might not increase their growth, yet on like soils other plants using much less of the same element

might grow much better with the same fertilizer added to them. The soil was too complex for this simple theory, called by some the "balance sheet" theory of plant growth. Yet the idea was not altogether bad; many of the facts these early scientists had were significant, but they didn't have enough facts. By using what they had and by trying many new ways of growing crops they did succeed in increasing the yields of grain in Europe a great deal. They did this even though they didn't always know the correct reason why.

While the people in western Europe were thinking about soils mostly in terms of getting bigger yields of crops to feed a rapidly increasing population, those in eastern Europe, especially in Russia, were thinking about soils in terms of a great undeveloped empire. Russia was a vast country with many, many kinds of natural vegetation, many different climates, and many kinds of soil. There were deserts with meagre plant growth and gray soils, great areas of land with short grasses and brown soils, a large belt of country with black soils—the famous wheat lands of Russia—light colored soils under a mixed forest, great sweeps of tundra, and many more. Western Europe was squeezed into a small space, but in Russia the traveler could not avoid noting that over great sweeps of country a certain climate, a certain general type of vegetation, and a certain group of soils went together. Scientists in Russia began to examine the soil itself—something those in western Europe hadn't done very much. This was easier to do in Russia because virgin soils—soils that had never been plowed—could be studied and compared with one another and with cultivated soils, while most of the soils suitable for growing crops in western Europe had already been cultivated for centuries.

From these new studies in Russia it was noticed that soils are made up of layers, or horizons. Each soil has certain horizons arranged in a particular way. From the top of the soil down into the parent material, from which the true soil has developed, a section including all the horizons taken together is called the soil profile.

The Russian scientists studied these profiles in relationship to the climate, vegetation, slope, rocks, and age of the soil. They began to classify soils and discover, not only how they were formed, but what crops were best suited to them and how they should be managed. When these new facts were added to those discovered in western Europe much better ideas of the soil were developed. In America the ideas of western Europe were first accepted, but not very eagerly since there were so many exceptions. A few scientists in this country began to develop different notions about the soil—more like those of the Russians and at about the same time, 1870.

Except for a very few men, there wasn't a great deal of study of soils in America until quite recently. There was so much new land to use that people in America didn't realize they had any really serious land problems until after the 20th century was well begun. A few individuals did. In the old magazines and agricultural books there are some excellent papers about soils and the need for better care of the soil. Some of these were written even before the Revolution, but mostly in the first half of the 19th century. By 1900 several people were working. Around 1915 the ideas of the eastern Europeans were introduced and since 1920 progress has been more rapid. Most of the early studies of soil in western Europe and America were more or less incidental to some other study. The scientists were agricultural chemists, geologists, or

botanists, or had some other principal interest. Not until there was a large body of knowledge about the soil itself could there be said to be a soil science. But the name makes no difference. Much of what we know about soils now was learned long ago.

Now it is known that soils are not simple storage bins. There are ways by which the soil maintains its fertility. As leached surface material is washed away by water—a tiny bit at a time—new fresh material from beneath is worked into the soil; the soil profile gradually sinks into the land over the centuries. Sometimes this action goes too rapidly and the soil washes away faster than new soil forms, especially when steeply sloping soils are cultivated. There are millions, billions, of small micro-organisms (bacteria and fungi) in each small clump of soil. These live on the organic matter and produce compounds that contain the elements needed by plants in forms they can use. One of the important elements needed by plants is nitrogen. There is an abundance of this element in the air but plants cannot use it in that form. It must first be chemically combined with oxygen or hydrogen, the two elements that form water. Certain organisms in the soil can do this—nitrogen-fixing organisms. Plants send down their roots, some very deeply, and take up elements that they leave near the surface to be used again when they die. Thus under natural conditions the elements are drawn from the whole soil to the depth of the roots, returned to the surface, and washed down into the soil again with the rains.

This mutual influence of soil and plant is very important. The plant requires a soil that can supply its needs and the characteristics of the soil are determined, in large degree, by the plants. First, the plant must have a place

to obtain a secure foothold. If the soil is too shallow over hard rock or water, roots cannot penetrate deeply and many kinds of plants cannot grow. Trees will be blown over easily by the wind if their roots are all shallow.

The plants use a good deal of water and must be able to get enough from the soil. Certain plants, like those of the deserts, may be able to use water if rains come only at great intervals or they may be able to get a very tiny but continuous amount through a large deep root system. Most plants grown in fields and gardens must have a continuous supply—not too much or too little. The soil must take in the water during rains, let the excess drain through and away, and hold enough for plants until the next rain.

The roots of most plants require air. If the soil has too much water in it, there will be no room for air. Of course, there are many plants that can grow with their roots in the water, but most crop plants will die if their roots do not have air as well as water. Also to some extent, the temperature depends upon the soil. Wet soggy soils warm up slowly in the spring as compared to those that are well drained and porous.

Most of the nutrients for plants come from the soil. The following list of elements includes those thought to be essential for plants. Few if any of these exist as such in the soil; instead, they are in chemical combination with other elements. Thus the elements must be present in particular combinations to be useful to plants.

Carbon (C) [1]—From the air, in combination with oxygen as carbon dioxide (CO_2).

Oxygen (O)—From the air and water.

Hydrogen (H)—From the air and water.

[1] In parentheses is given the chemical symbol for the element.

Nitrogen (N)—From the soil (indirectly from the air through the action of certain bacteria, especially those growing with the clovers, alfalfa, and other legumes).

Phosphorus (P)—From the soil.

Potassium (K)—From the soil.

Calcium (Ca)—From the soil.

Magnesium (Mg)—From the soil.

Sulphur (S)—From the soil.

Iron (Fe)—From the soil.

Manganese (Mn)—From the soil.

Copper (Cu)—From the soil.

Zinc (Zn)—From the soil.

Boron (B)—From the soil.

The last five of these are needed in only very small amounts by most plants. Several other elements are found in plants and it is not absolutely known whether they have any essential functions in growth or not. Very likely some of them do have, but methods of research are not yet precise enough to detect them. Both sodium (Na) and chlorine (Cl),[1] for example, are common in plants. But up to the present those listed are the only ones known definitely to be necessary. A few of the "extra" elements taken up by plants, although not thought to be essential to their growth are, nevertheless, essential to the growth of animals. Thus certain grasses and vegetables that may grow well and look normal are not good food because of a lack of some elements, like cobalt or nickel, needed by grazing animals or humans. If these foods are eaten continuously, "deficiency" diseases develop. Again, some of the "extra" elements, like selenium, that plants

[1] When combined these two elements produce sodium chloride or common table salt, found only sparingly in most soils.

sometimes take up may harm them little or not at all, but may be toxic to animals or humans who eat the plants.

Plants also use some of the organic compounds in the soil manufactured by other plants and micro-organisms. Recently it has been suggested that certain vitamins stimulate the growth of plants. Perhaps there are other organic compounds of importance. At any rate it has been known for a long time that plants grow better if they have organic matter; that is, certain kinds, like leaf mold or manure. Some other organic compounds will poison plants. Plants can be grown well in pure sand cultures with all the necessary mineral compounds present in proper balance, but if a little organic matter is added, say leaf mold from the forest floor, they grow much better. Because organic matter often has beneficial influences on plant growth and because all the reasons are not clear, some have attributed a sort of mysterious power to this material. Of course, it has no such power and its influence in any soil depends upon the kind of organic matter and the other components of the soil. It can be even harmful.

These elements taken up by plants in the materials absorbed through their roots and leaves are called nutrients, but they are not the food of the plant. From these elements the plant manufactures its food. Green plants in sunlight form sugars and other organic compounds from the carbon, hydrogen, oxygen, and other elements. These foods are used by the plant itself to nourish its cells. From them they obtain energy for their life processes. The excess or stored food may be eaten by animals. The elemental materials are spoken of as plant nutrients but sometimes, incorrectly, as plant foods. The

foods are the organic compounds, such as those stored in the roots of carrots and sugar-beets, in the fruit of apple trees, and in the stalks of sugarcane.

In the world there is an enormous number of combinations of soil characteristics. There are variations in the content of the several chemical elements, in the forms in which the elements are chemically combined, in the water relations, in depth, and so on. Some soils are especially suited to certain plants, but other plants may not be able to grow in them at all and require an entirely different combination of characteristics. People have discovered these things by "trial and error." But by the time they learned, many may have lost everything—wealth, labor, and spirit. If such bad relationships between soil and man's use of the soil are to be avoided these things must be known in advance and account taken of them. As the poet Vergil advised many years ago:

> Take care to learn before and to observe,
> The winds, and changing temper of the air,
> The soil, the native genius of the place,
> What fruit it bears and what it will refuse.

2.

THE BUILDING MATERIAL FOR SOILS

MOST soils are developed largely from broken rocks.[1] When the soil in a field or garden is examined, it is seen to be composed of living and dead organic matter, glue-like matter with individual particles too small to be seen with the naked eye, and all manner of small pieces of rock from tiny sand grains to large stones in many instances. The forces of nature, patiently over the years, have produced these materials, mostly but not entirely from the hard rocks on the surface of the earth. From the rocks come most of the building stones—the raw materials—from which soils are made. Of course, a great many entirely different kinds of soil may be built from the same rocks, just as a church, a factory, a row of cottages, or a swimming pool might be built from the same kind of bricks. Almost identical houses can be built with different kinds of building stones; similarly, almost identical soils may be developed from different rocks.

Deep in the earth there is no living matter. The processes of change and movement are strictly physical and chemical. On the surface of the earth is the living matter. The processes of growth and reproduction of plants and animals are called biological. Both sets of processes meet and mingle in the surface film of the earth's crust to form

[1] A few are developed from peat, consisting mainly of organic matter.

the soil, which is neither strictly physical nor strictly biological but a combination of both.

Unless one lives in a nearly flat country, it is easy to see different kinds of soil within a few miles of home. Some may be lighter colored than others; some may be stonier than others, some may be sticky when wet whereas others are not—there may be all manner of differences in appearance, just as there are great differences in the crops, the trees, and the kind of homes on them. As long as the observer stays within an area having no great changes in climate or native plants, these differences are closely related to variations in slope and in the nature of the rocks. Because of this fact people have sometimes placed too much importance upon the particular kind of rock that underlies a soil.

The kind of rock is important but not more important than climate, the plants, the slope, or the time. Although a house may be made mostly of brick or stone, we know that the arrangement of the rooms, their shape and size, and the use of small quantities of paint, iron, glass, wood, cloth, and paper have much to do with its final appearance and comfort. Many animals eat the same food and drink the same water, but they use these so differently in growth as to be quite unlike. Although some of the soils in New York have developed from the same kinds of rocks as some of those in northeastern Montana, they are entirely unlike. Those in New York have formed under the trees with enough rain to cause strong leaching while those in Montana have formed under short grasses and scanty rainfall.

Perhaps if more is said in this vein the reader will think there is no need to study rocks in order to learn of the soil. That would be unfortunate; yet it would be equally

unfortunate for one to get the notion that if he knew all about rocks he would know a great deal about soils.

Rocks are composed of minerals. They are classified and given names according to the amounts of the different minerals in them and their other characteristics, such as hardness and texture, due largely to the manner in which they were formed. The minerals that compose rocks are particular chemical combinations of the elements. For example, quartz (SiO_2) is a hard mineral composed of silicon and oxygen. When pure, this mineral is clear, like glass, but with small mixtures of other substances it may have many colors. Orthoclase is another made up of silicon, aluminum, potassium (one of the elements necessary for plant growth), hydrogen, and oxygen. Much of the phosphorus in rocks comes from a mineral, apatite, composed of calcium, oxygen, and fluorine as well as phosphorus. There are thousands of minerals and it would lead us too far away from our main subject to deal with all of them. But it would be helpful to know something about the elements that compose them.

Taking the earth as a whole—all the land, air, and water—there are 9 elements that make up the great bulk. These are:

Oxygen (O) *—This is one of the principal elements in the air and makes up a large part of water. It is combined with many other elements to form minerals. It is essential to living things and is included in organic matter, combined with other elements.

Silicon (Si)—This element is one of the principal ones in rocks. It is not found naturally in pure form, but is commonly combined with oxygen to form quartz or other forms of *silica*.

* The chemical symbol is placed in parentheses.

Aluminum (Al)—Although not found in nature in pure form, it can be extracted from minerals and shaped into useful forms. It is combined with silicon, oxygen, and other elements in many rocks.

Iron (Fe)—In nature iron is found most commonly combined with oxygen, and frequently with other elements also. Most red soils owe their color to this combination of iron and oxygen. It is essential to plants in small amounts.

Calcium (Ca)—Commonly calcium is found in combination with carbon and oxygen, as in limestone or marble (or in the sidewalk); although it also combines with silicon, aluminum, and other elements. It is essential to plants.

Magnesium (Mg)—This element is found under somewhat the same conditions as calcium, yet there are also many combinations of magnesium and iron with other elements. Magnesium is one of the elements in chlorophyll, the green matter in living plants.

Sodium (Na)—Sodium is found in combination with silicon and other elements. It is commonly combined with chlorine to form sodium chloride, common table salt. This salt is very soluble and is found in appreciable amounts only in the soils of depressions or seepy places in regions where the rainfall is scanty, or near the ocean. It is not essential to plants, but if potassium is scarce, some plants seem to be able to use it in place of a part of the potassium.

Potassium (K)—This element is similar to sodium in several ways; it is never found by itself but in combination with other elements. It is essential to plants.

Hydrogen (H)—This element is contained in the air in small amounts and, with oxygen, makes up water.

Like oxygen, in pure form it is a colorless gas, and in oxygen burns to form water. If large amounts of the two are brought together they will explode violently.

Although these 9 elements make up the great bulk of the earth there are five more that should be added to this list because of their importance to soils and plants.

Carbon (C)—This element is found in nearly pure form as charcoal, graphite, and diamond. With oxygen and hydrogen it makes up the great bulk of dry organic matter, such as this paper, wood, and sugar. Carbon is combined with oxygen in the air to form carbon dioxide (CO_2—one atom of carbon and 2 of oxygen to form one molecule of carbon dioxide). Sometimes carbon and oxygen combine to form carbon monoxide (CO—one atom of carbon and one of oxygen) which is poisonous to men and animals and is contained in the exhaust from gasoline motors. Carbon is also combined with oxygen and some metallic element, like sodium, potassium, calcium, or magnesium, to form a group of salts called *carbonates*. (Na_2CO_3, K_2CO_3, $CaCO_3$, and $MgCO_3$).

Nitrogen (N)—The air contains about 78 percent nitrogen as an inert or rather inactive gas. It is essential to all life and is combined with carbon, hydrogen, oxygen, and sometimes phosphorus or sulphur to form the *proteins* in plants and animals. It is not contained in rocks, except those, like coal, that may have organic matter in them. In arid regions deposits of nitrogen salts sometimes occur, like the famous Chilean nitrate beds.

Phosphorus (P)—Phosphorus is found combined with oxygen and other elements, such as calcium, in rocks. It is found in soils combined with oxygen and calcium or magnesium and also in the organic matter left by pre-

vious plants. The relative availability of the phosphorus to plants varies greatly in different soils. Sometimes the phosphorus is combined with aluminum or iron in relatively insoluble forms and, even though the total amount in the soil may be high, the plants may suffer from a lack of it. This element is necessary for plant growth and forms a part of certain essential proteins. Because it is often lacking in soils and because of the critical need for it by animals and people for growth and health, special importance must be given it.

Sulphur (S)—This element is found combined with oxygen and other elements, especially in *sulphates,* such as $CaSO_4$ (gypsum) and $MgSO_4$ (Epsom salts). Some sulphur compounds contained in the air, produced from burning fuel or decomposing organic matter, are absorbed by the water when it rains and by the moist soil. It is essential to plants and forms a part of certain important proteins.

Chlorine (Cl)—Chlorine is not essential to plants although they absorb some of it. It occurs in combination with calcium, magnesium, sodium, potassium, and other elements to form *chlorides,* like NaCl (common table salt). Most of these salts are very easily soluble.

These last five elements—carbon, nitrogen, phosphorus, sulphur, and chlorine—plus hydrogen and oxygen from the first group, might be called the active elements, while the others might be looked upon as the less active or passive group. Of the passive group silicon is ordinarily the most abundant. It is commonly in the form of silica (like pure sand) which is relatively very insoluble in water, especially under acid conditions; frequently it is combined with aluminum and oxygen. Aluminum and iron are commonly combined with oxygen (and other ele-

ments) and such compounds are relatively insoluble, but, in contrast to silica (and silicates), are more soluble under acid conditions than alkaline conditions. The bases calcium, magnesium, sodium, and potassium are frequently combined with other elements to form salts which are relatively soluble, as compared to silica. Although there are exceptions, the salts of sodium and potassium found in the soil are ordinarily more soluble than those of calcium and magnesium. There are many other elements that make up some part of the soil.

These elements, and other less important ones, make up the minerals. Each mineral has a fairly definite combination of elements. They vary from one another, not only in chemical composition, but in solubility, hardness, color, and crystal form. Rocks are composed, in turn, of combinations of minerals. Thus granite is composed of quartz and feldspar plus some dark colored mineral like mica or augite (Figure 1). But many rocks are even less definite in their mineral composition. During the weathering process, some of the minerals are changed—changed to a new crystalline form as well as in chemical composition. Many disappear, and entirely new and different ones take their places.

Summarizing, the elements making up the bulk of the soil can be placed conveniently into four main groups, more or less arbitrarily according to chemical properties: (1) Silica (SiO_2), (2) sesquioxides (Al_2O_3 and Fe_2O_3), (3) the so-called bases (CaO, MgO, Na_2O, and K_2O), and (4) miscellaneous, such as MnO, P_2O_5, and so on. The approximate amounts of these main constituents in several soils are shown in the graphs in Figure 14.

There are three general classes of rocks according to their mode of formation, igneous, sedimentary, and meta-

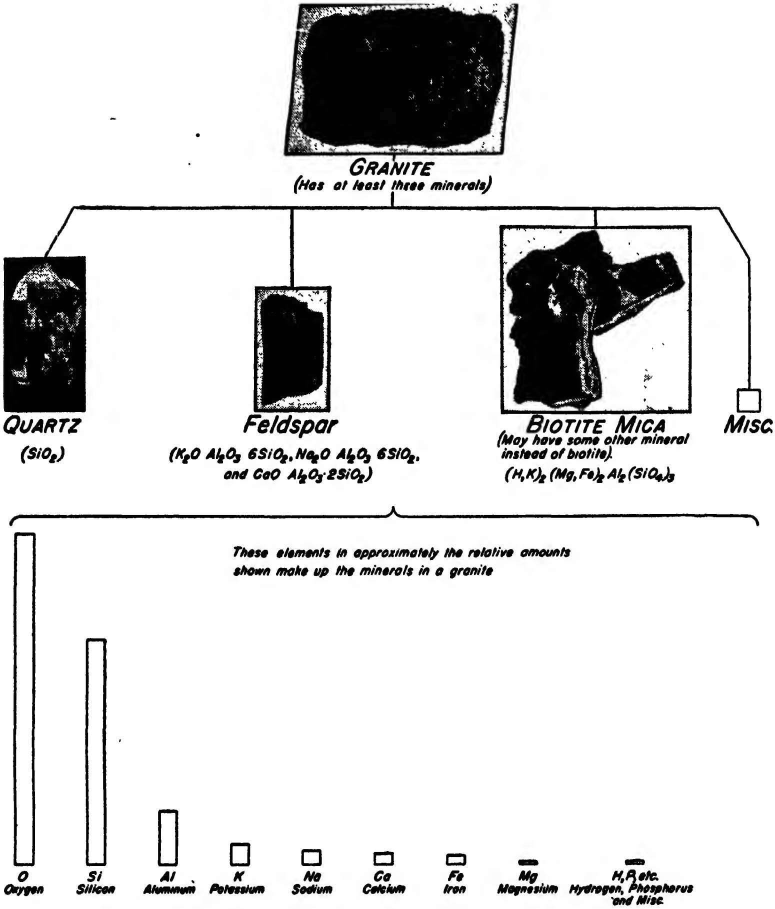


FIGURE 1. In the lower part of this diagram are shown the relative proportions of the elements in an ordinary granite, one important igneous rock. These elements make up the minerals that go together to make up granite. Usually quartz is most abundant and mica (or some similar mineral) the least abundant in granite. Other primary rocks are made up of other combinations of minerals.

morphic. Sometimes the igneous rocks are spoken of as primary, while the others are called secondary, since they are formed by changes—sometimes great changes—in the primary rocks. Igneous rocks are produced by the cooling of molten rock material. If the molten matter cools very rapidly, like the lava that flows down the side of a volcano, a more or less uniform, smooth, hard, glassy rock results. If the molten material cools very slowly the individual minerals separate out as large crystals, as in granite. If the rock is very high in its content of silica it is said to be acidic, whereas if it has a high content of the minerals containing much calcium, sodium, magnesium, and other elements instead of silica it is said to be a basic rock. Other things being equal, such as slope, climate, vegetation, and age, in regions of moderate to high rainfall somewhat more fertile soils are produced from basic rocks than from acidic rocks.

Sedimentary rocks are those formed from the cementing together of sediments. As a result of the continual washing of the land, deposits of sand and mud are laid down in lakes, in the sea, and along stream courses. These soft deposits are, broadly speaking, rocks—unconsolidated rocks. But ordinarily they are not thought of as rocks until the individual grains have been cemented together to form a hard mass. Thus sandstone is formed from the cementing together of particles of sand by compounds of iron, silicon, or calcium. Similarly shale is cemented or consolidated mud, and conglomerate cemented gravel. (Ordinary cement sidewalks and pavements are a kind of man-made conglomerate—gravel cemented with calcium compounds.) Some plants and animals can take from the water large amounts of calcium, which is built into the body of the organisms. As these

organisms die deposits of marl (or bog lime) rich in calcium carbonate ($CaCO_3$) are built up, more or less mixed with impurities. Limestone is produced by the consolidation of such masses of material. Since these sedimentary rocks are made from water-laid deposits, they may exist in small bands or sheets one over the other, or in thick masses. They also vary a great deal in chemical composition. Thus a shale may be developed from thoroughly leached muds with very small amounts of the essential plant nutrients. Relatively poor soils would be expected from such rocks. Or again a sedimentary rock may be about halfway between shale and limestone.

In humid regions where there is much leaching, soils developed from limestones are usually more fertile than those developed from most other rocks, especially on sloping lands. On soils developed from steeply sloping shales in the Appalachians, for example, only forests may be grown, whereas good pastures may be produced on soils developed from steeply sloping limestones in the same region.

Metamorphic rocks are those produced through the action of great heat and pressure on other rocks, igneous or sedimentary. Thus a hard slate is developed by great heat and pressure upon a shale. Marble comes from limestone, quartzite from sandstone, and gneiss from granite. Some of these differences that are very important to a geologist, interested in building-stones and mining, may not have a great importance in soils unless one is making very minute comparisons. Ordinarily the slates and quartzites are very resistant to weathering and give rise to poor soils.

Rocks, especially the igneous rocks, may occur in large masses, but usually they exist in layers or irregular masses.

Sometimes the rocks have been patiently folded and broken during the long course of the earth's history. Mountains have been forced upward, partly or wholly worn down by streams, and breaks and slides have taken place. Thus over a large area, one kind of rock may lie just beneath the surface mantle of soil. In other places, as in a hill-valley section like much of Pennsylvania, one may find shales, sandstones, and many other rocks within a short distance. Again the rocks may be covered with wind-blown sands or silts, with stream deposits, or with materials left by the glaciers. Thus in the northern part of the United States and along the streams and near the foot of the mountains, the soils are not developed from the rocks in place, but from materials deposited over the rocks.

The first step toward soil formation is the development of material—parent material—in just the same way as one needs bricks and other materials to build a building. The rocks—hard rocks—are not such material, not until they have been broken up into fragments so the roots of plants may extend themselves and find a foothold, water, and nutrients. Plants are the real makers of soil. Once they have started to grow, they themselves may assist in the process of rock crumbling, but, for the most part other forces are more important (Figure 7). It is incorrect to think of soil as broken rocks, as incorrect as it would be to think of a pile of bricks as a house. The breaking of the rocks into parent material for soil is largely a destructional process, while soil formation is largely a building process. Sometimes soil formation follows so closely that one can scarcely tell where one leaves off and the other begins. In Figure 55 is shown a young soil developing from weathered volcanic lava. Just as fast as the rock

underneath breaks up, the new particles are incorporated into the soil; and tongues of soil extend down in the cracks in the rocks. In many other places, soil formation is going on only in the upper 2 or 5 feet of thick accumulations of parent material over 100 feet deep.

Rocks are weathered by simply breaking into pieces, as in cracking or grinding, and by changes in chemical composition as, for example, when one or two elements are removed from a mineral, thus changing it to a different mineral. Both of these processes are greatly influenced by climate—the temperature and the amount of water.

The heating and cooling of rocks breaks them into pieces. When farmers have huge boulders to remove from the land in order to plow it—boulders too large to move in one piece—they frequently build a fire of brush and logs around it. As soon as the rock is hot, they rake the fire away and throw water on it. This sudden cooling of the surface causes it to shatter into pieces. It is the unequal heating and cooling that causes the breaking; at first the rock is suddenly heated on the outside while the inside is cool, then the surface is chilled. Similarly, when the rays of the sun strike a rock the surface is heated more rapidly than the inside. In the deserts this change in the temperature of the surface may be very great and very sudden. Since the rock expands when heated and shrinks when cooled, strains are set up that break it. Furthermore, the different minerals within the rock heat and cool at different rates and swell and shrink different amounts. If the changes in temperature pass from below freezing to above freezing and back again, the action of ice formation is added to the other strains. As water freezes, it expands about 9 percent with terrific force.

Thus the water in a crack of the rock may freeze, widening the crack; and when the ice thaws the crack may fill with water and the next freeze may widen it further.

Wind and running water may pick up pieces of rocks and carry them along over other rocks, grinding and polishing them in the process. In dry regions, where there are frequent sandstorms, the sand cuts out the soft rocks more rapidly than the hard rocks and thus produces some weird looking cliffs and pedestals. This wearing away of the land by wind and water is called erosion. Not only are rocks subject to weathering through erosion, but many soils have a portion of their surfaces removed from time to time by erosion. Some erosion is a good and necessary thing, but if it goes on too rapidly—more rapidly than soil formation—the soil may be injured.

The fine material carried by streams and redeposited is called alluvium. It is spread out by the streams in great alluvial valleys and deltas as along the Nile, the Mississippi, the Amazon, and other great rivers. Early civilizations grew up largely on these alluvial lands and probably today over a third of the people of the world get their food from soils developed from alluvium. Many of these soils are very fertile because a thin covering or film of fresh alluvium from eroding rocks is added to the surface every year or so during periods of high water in the river.

Ice is also another important agent of rock crushing. When ice and snow accumulate in great masses these slide over the land, scouring, crushing, and grinding the rocks as they go. These moving bodies of ice, or glaciers, are not very important today, except in the Polar regions, although a few may be seen in the high mountains of western United States, Alaska, and elsewhere. Many thousand years ago, however, great glaciers, called continental

FIGURE 2. Map showing the maximum extension of the great ice sheets in North America and the centers of ice accumulation. Note that New England and a large part of north-central United States has been glaciated, except for a small area in southwestern Wisconsin. In a large portion of these regions thick deposits of unconsolidated material were left over the country rock. (Courtesy of Wm. C. Alden, U. S. Geological Survey.)

glaciers, slowly crept down over much of modern Europe and a large part of the United States, including New England, the Lake States, most of North Dakota, parts of Montana, and as far south as the Ohio River (see Figure 2). At different times at least 4 of these great ice sheets came down from what is now Canada. In much of the country they went over the same area, but there are many places where some of the early glaciers left deposits not covered by later ones. Curiously enough, the glaciers passed completely around a large area in southwestern Wisconsin.

Rocks were picked up by the glaciers and ground into particles varying in size from boulders, cobbles, gravel, and sand down to fine clay. This finer material is sometimes called boulder clay or glacial flour. All of the material moved by the glacier or by streams in or at the edges of the glacier is called glacial drift. As the ice melted, the rock material was dropped. If the ice melted as fast as it slid or flowed forward, material was piled high in hills at the end or at the margin of the ice. If the ice melted faster than it moved forward the rock material was dropped to make smooth or undulating plains. This material dropped directly by the ice itself is called glacial till. It consists of a mixture of clay and sand with a few or many boulders.

While the glaciers were on the land, and as they receded, there was a great deal of flowing water. This water picked up much of the glacial material and deposited it in glacial lakes, along glacial streams, or in great outwash plains. Many large areas of such smooth deposits can be seen in the United States as, for example, the famous Red River Valley of the North, partly in North Dakota and partly in Minnesota. This large area is really

not a river valley at all, but an old glacial lake, called glacial Lake Agassiz, in which the Red River flows north toward Hudson Bay. The smooth land of the Saginaw valley in Michigan extending around the "Thumb" down into Ohio and along the shore of present Lake Erie was also once covered by a glacial lake. There were many others throughout the region once glaciated. In the West there are a great many old lake basins, once filled with water but now dry, or nearly so. Those in the dry regions are apt to be salty.

The wind also moves fine particles, especially during periods of great dryness. Along lake and ocean beaches and in deserts there are frequently large areas of sand—loose sand easily blown by the wind in peculiarly shaped mounds or hills. A strip around southern and eastern Lake Michigan is noted for the beautiful sand dunes. As they become "fixed" with vegetation, soil begins to form, but if fire or unwise clearing of the land removes the vegetation they may begin to blow once more. Such dunes may move along several miles in the course of a few years unless checked by some obstruction. In many of the large deserts they are constantly shifting about.

During periods of great dryness fine material called *loess* is picked up by the wind and carried a little way or great distances to be deposited as a thin film or as a thick mantle over other land. This material may be picked up out of great river valleys, out of old lake basins or out of other formations, leaving the coarser material behind. In Nebraska, for example, there is a great area of sand hills, old dunes, that were left after the fine material was nearly all blown out of them. It is thought that some time after the glaciers came over the country there was a period of great dryness when much of this fine material was laid

down as a mantle over a large area of the country, including parts of Iowa, Illinois, Nebraska, Kansas, Missouri, southern Minnesota and Wisconsin, western Kentucky and Tennessee, and elsewhere (Figure 3). Recently this action went on in a small way—that is, small from the standpoint of geological time and results—in the so-called "Dust Bowl" of the southern Great Plains. If soil blowing were to continue for a great many years in the Dust Bowl, sand dunes like those in northwestern Nebraska would be left while the fine particles would be deposited elsewhere as loess. Some of the best soils in the United States are developed from this fine, silty material. It is not proper to speak of "loessial soils," however, except in a very general sense, because there are a great many different kinds of soil, some very much better for crops than others, developed from loess, depending upon the vegetation, climate, and relief.

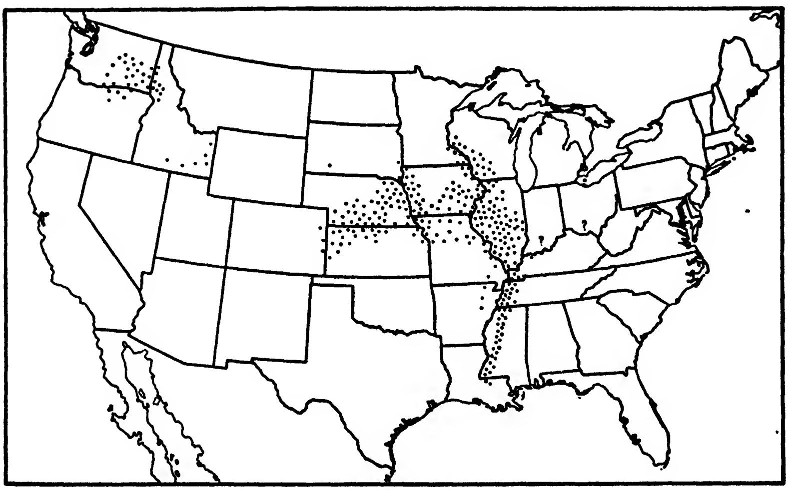


FIGURE 3. A sketch map showing the approximate location of the main deposits of loess from which important soils are developed. (After Marbut and maps of the Geological Survey.)

The chief agent of chemical weathering or decomposition is water. Although some minerals are very easily soluble in water, others are only very slightly soluble. But even though they be ever so slightly soluble, given great periods of time, appreciable amounts will be dissolved. As different elements are dissolved out by the water trickling through the rocks, other combinations are left behind and new ones form from the meeting of the elements in solution. As the water, charged with the soluble materials, moves to another place, either over the surface or through the rocks, some of it may evaporate and drop the materials previously held in solution. In many places, as along the Great Valley of western Virginia, great caves have been formed by the gradual dissolving out of the more soluble materials in the limestone rocks. Then frequently water may drip into these caves after it has passed through rocks dissolving some of the minerals. As the water slowly drips into the caves and evaporates, grotesque structures are built that hang from the ceiling like icicles, called stalactites. When built up from the floor, like an inverted icicle, they are called stalagmites. Sometimes these meet to form columns. Usually they consist mostly of calcium carbonate ($CaCO_3$) but often are highly colored with iron compounds, clay, etc.

The action of the water is increased by having carbon dioxide (CO_2) dissolved in it. Since carbon dioxide is in the air and is soluble in water, more or less of it is dissolved in water exposed to the air. Such water is really a weak carbonated water—like that at the soda fountain. In order to illustrate this process of chemical decomposition, we might look at what may happen to one mineral, feldspar—one of the minerals in granite. One kind of

feldspar contains oxygen, silicon, aluminum, hydrogen. and potassium as follows: $K_2O \cdot Al_2O_3 \cdot 6\ SiO_2$. By the action of water, potassium is removed and a part of the silicon as well, until there is left behind another mineral, kaolin: $Al_2O_3 \cdot 2\ SiO_2\ 2\ H_2O$. The potassium is dissolved away, and possibly redeposited somewhere else as potassium carbonate (K_2CO_3). If the decomposing feldspar is in reach of a plant root, some of the potassium may go into a plant. The silicon may be deposited somewhere else as quartz (SiO_2). Under extreme weathering with the relatively high temperatures of the tropics this kaolin may be even further changed, by loss of the remaining silica, to gibbsite: $Al_2O_3 \cdot 3\ H_2O$. In the humid tropics decomposition may be so extreme that nearly everything is removed except aluminum and iron, left largely in the forms of Al_2O_3 and Fe_2O_3.

The iron compounds are of special interest because they have such a marked influence upon the color of both rocks and soils. When the iron is kept from air—isn't associated with the maximum amount of oxygen—it is called *reduced*. This reduced iron has only one atom of oxygen for each atom of iron (FeO) and is called *ferrous* iron. Compounds of ferrous iron usually give a bluish-gray color to the soil. When found in the soil, they indicate poor drainage in the soil and a lack of air. These compounds give the characteristic color to the blue clay often found in the subsoil of poorly drained soils. Upon long exposure to the air this iron changes to the *ferric* form, which has 3 atoms of oxygen for each two atoms of iron (Fe_2O_3). This compound is ordinarily red in color. With varying amounts of water attached to the Fe_2O_3, different minerals are formed; and with increasing amounts of water the minerals are brown and then yel-

low in color.[2] The ferrous iron is more easily soluble in water than the ferric. Frequently in swampy places most of the iron is the reduced or ferrous kind, and if the water from the swamp drains into some large ditch or stream bank where it comes in contact with the air, the iron will be changed to the less soluble, ferric kind, and settle out to form deposits of bog-iron which is sometimes mined as an ore.

Chemical weathering changes the volume of different materials in the rock and thus causes strains that tend to break it into pieces (Figure 4). The breaking of large masses of rock into small pieces greatly increases the surface subject to the chemical action of water and the acids and other materials dissolved in it. Thus these two processes of disintegration and decomposition aid each other.

In many parts of the world the parent material for soil accumulates in place just above the rock from which it is developing. Thus, ideally, the soil makes up the surface few feet and is underlain by the weathered rock; and this, in turn is underlain by partially weathered rock and finally by the hard rock. This formation of soil material is called *residual* weathering and the weathered rock residual material.[3] There is much soil developed from residual material, but more has been developed from *transported* materials. The transported materials are usually classified according to the agent responsible for their movement—wind, water, ice, or ice and water. Besides these mineral deposits are the organic ones, those com-

[2] The fineness of the individual particles of iron oxide also affects the color of the mass, but to what extent this fact is important in modifying soil colors has not been investigated adequately.

[3] Sometimes the expression "residual soil" is used for a soil developed from such materials as contrasted to "transported" soils. This is incorrect. It is the *parent material*, not the *soil*, that has been transported. All natural soils are developed in place.

posed of peat accumulated in poorly drained places from plant remains. Some soils develop from these materials.

The rate of weathering depends upon the hardness of the rocks and the relative activity of the several forces. In cool dry climates decomposition is slow while in hot wet climates it is rapid. On steep slopes, the products of weathering slide or wash down and it may require mil-

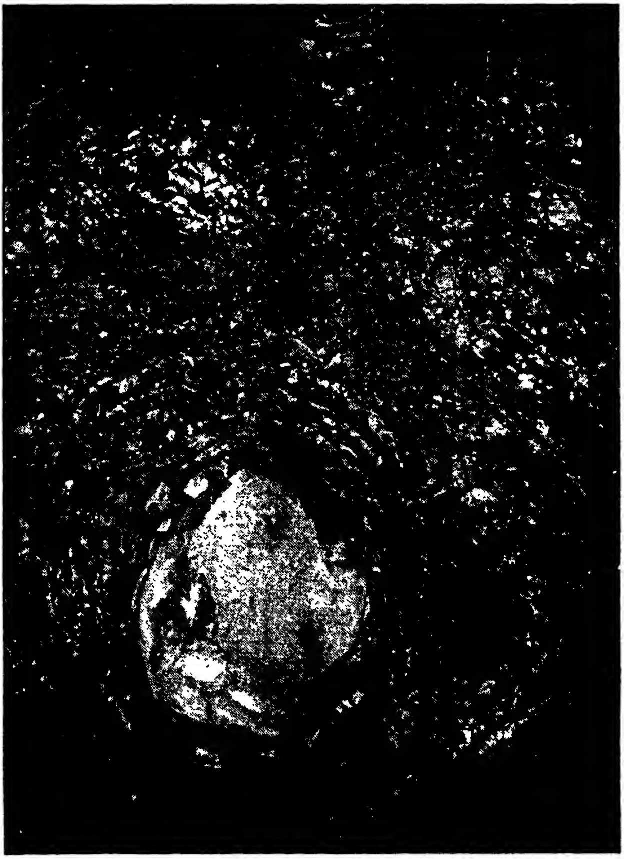


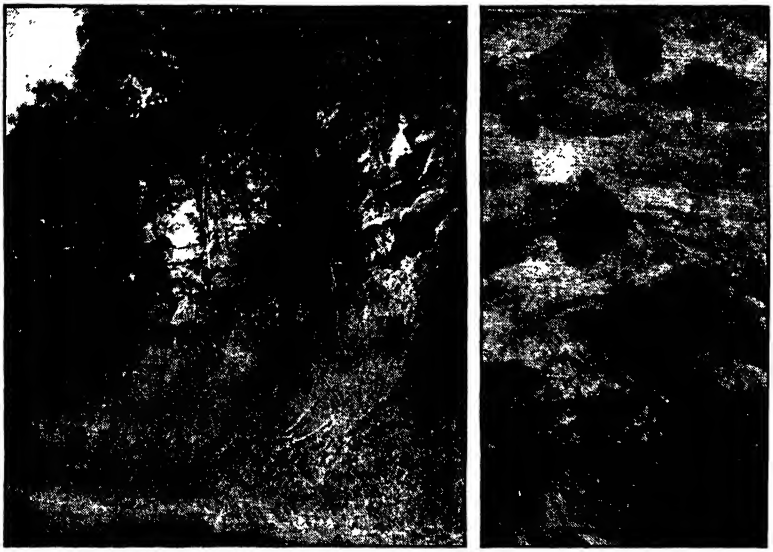
FIGURE 4. A boulder imbedded in lateritic material produced by the intense weathering of the tropics. Note how the material has separated in concentric rings, or shells. (Hawaii.)

lions of years for the loose rock materials to come to an angle of repose; while they accumulate more rapidly in place on smooth land. Elsewhere streams or wind or ice may deposit materials over the rocks. During times of flood, thick deposits of fine material from which soil can be formed may be laid down in a few days, or even hours. On steep slopes weathering may go on for millions and millions of years before soil formation can begin—before any soil material is developed. Some people speculate about how much time is required "to build an inch of soil material." The answer could well be, "somewhere between 10 minutes and 10 million years."

Although the history of a true soil starts with the beginning of vegetation on the rock material, there is a long and thrilling story behind this beginning, just as our breakfast is prepared in the kitchen, yet each ingredient has a long history before it ever gets to the kitchen. Also geological changes are progressing as soil formation proceeds. Sometimes these changes are drastic enough to change the whole course of soil formation, or even destroy the soils or cover them. An erupting volcano does this quickly and dramatically, but usually the sinking of land beneath the sea, the elevation of mountains, and the cutting of streams into a high plain are very slow processes.

Old soils have been found buried beneath volcanic lava, alluvium, or glacial drift, soils that may have been formed under an environment of climate and vegetation quite unlike the environment that produced the existing soil at the surface (Figure 5). Only recently have soil scientists and archaeologists begun to study these old buried soils and reconstruct the history of their formation. Bones and implements buried in them yield clews to their use by prehistoric animals and ancient man.

Soils do reflect this geological history. When the great glaciers crept down over large parts of North America, they plucked large masses of rock material from the formations over which they passed—granite, limestones, shales, sandstones, and others. Some of the fragments were simply scoured and rounded into boulders or pebbles, while others were ground into fine clay. And the whole mass was more or less mixed. Much of this material, this glacial debris, was sorted by water in glacial lakes or by streams flowing on and from the melting ice. As the climate became warmer again, the retreating gla-



A B

FIGURE 5. A soil buried by lava. (A) In this photograph can be seen an old soil, some 6 to 10 feet in depth, overlain by younger lava from which a new soil is developing. (B) A close view of the lava just above the buried soil showing the holes formerly occupied by trees growing on the old soil when the lava flowed over it. The top of the buried soil is visible in the lower part of the picture. The study of buried soil is a special branch of soil science or pedology—paleopedology. (Hawaii.)

ciers left an almost infinite variety of lakes, stony hills, level sand flats, stream beds, and gently rolling plains. As the ice receded, vegetation followed and soil formation began.

Sometimes evergreen forests of spruce and pine took over; in other places there were hardwood trees, like the beeches and maples. In the wet places there came swamp forests of cedars and spruces, or open stands of rushes or low shrubs. In the drier regions, grasses covered the earth. As the climate changed, the vegetation changed; so grasses sometimes choked out the trees and forests sometimes crowded over the grasslands.

Thus was created a host of different soils, each with its own history. These did not come into being quickly, like this telling, but slowly, very slowly and with infinite patience. Man can scarcely form a concept of nature's patience, variety, and detail, nor of the quiet, merciless struggle of plants seeking a foothold, a place to live and reproduce their kind. And finally each plant finds itself limited to certain kinds of places where it can live with a few others and defend itself against extermination.

But never is the landscape fixed. Between the broad, infinitely slow cycles of mountain building and destruction and the almost hourly differences in sunshine and moisture are other cycles of change, some very slow, some seasonal. We must separate these processes to study them, but without forgetting that they operate together and pile upon each other over periods of abundant time, where nothing dominates and nothing is omitted.

3.

LIFE AND THE SOIL

THE title of this chapter may be misleading. Although in one sense the soil is not alive, in a practical sense it is. Life and the soil always go together. Most life goes back to the green plant. Animals eat the animals that eat the green plants; and green plants grow in the soil. But more than that, the most important characteristics of different soils are produced by living organisms—the green plants and other living things associated with them. Truly it may be said, "no soil without life, no life without soil." Before life came to Earth and spread a green mantle over the land, it must have been a dreary place. Perhaps it looked something like the surface of the moon as seen through a powerful telescope—or perhaps more like the desert without even its scanty vegetation. The hills and valleys had sharp angles, rocks rolled down the slopes to form huge piles, and the jerky streams cut sharp gorges.

As plants begin to grow in the loose rock material they cause many changes (Figure 6). They even assist in the weathering process itself (Figure 7). The roots go into the ground and take water and nutrients from the lower layers as well as from those near the surface. The water, the nutrients, and the carbon dioxide from the air—these are combined by the plant, under the sun's rays, into new materials, organic compounds. These organic com-


A
B

pounds, like sugar, are the food of the plant. From these foods the plant lives and produces its structures. It is this stored food of the plant that is eaten by people and animals. When the plants and animals die, their remains again go back to the soil—to the surface. Thus when plants are removed from the soil, harvested, this natural cycle is changed—a fact that the farmer must understand (see Figure 13).

The leaves, twigs, and roots left by the plants serve as food for micro-organisms. These small organisms, too small to be seen with the naked eye, include small animals, fungi (small plants without green color, like the molds), and bacteria, tiny living things with only one cell. Some of these bacteria can live without air (anaerobic bacteria) and others must have air (aerobic bacteria). Also larger animals, like earthworms, live on this organic matter. They pull the bits of leaves down into the ground and help to mix them with the mineral matter.

Some plants feed very heavily on such elements as calcium, magnesium, and potassium, others lightly. Some produce and return to the soil much organic matter each year, others little. Some kinds of organic matter are decomposed by the micro-organisms rapidly, other kinds slowly. Thus the tall grasses, like those native to Iowa and eastern North Dakota, feed much on such bases as calcium. The organic matter decomposes rapidly. Usually the grasses bring bases to the surface fast enough to prevent the soil from becoming acid, to counteract fully

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FIGURE 6. (A) Plants are finding root, and soil formation has barely started on this mountainside. Such soils are called Lithosols. (B) A nearly mature forest has established itself on this stony mountain slope. The true soil is very thin indeed and would be classed as a Lithosol, but enough soil characteristics have developed to show that in time a Podzol will be formed. (Maine.)

the weak carbonic acid of the rainwater. Evergreen trees, however, such as the pines and spruces, feed lightly on bases, returning only a small amount of organic matter to the surface each year, and this decomposes slowly. Somewhere between, usually a little closer to the evergreen trees than to the grasses, are the broad-leafed or deciduous trees, such as the maples and poplars. They shed their leaves each year and these decompose more rapidly than

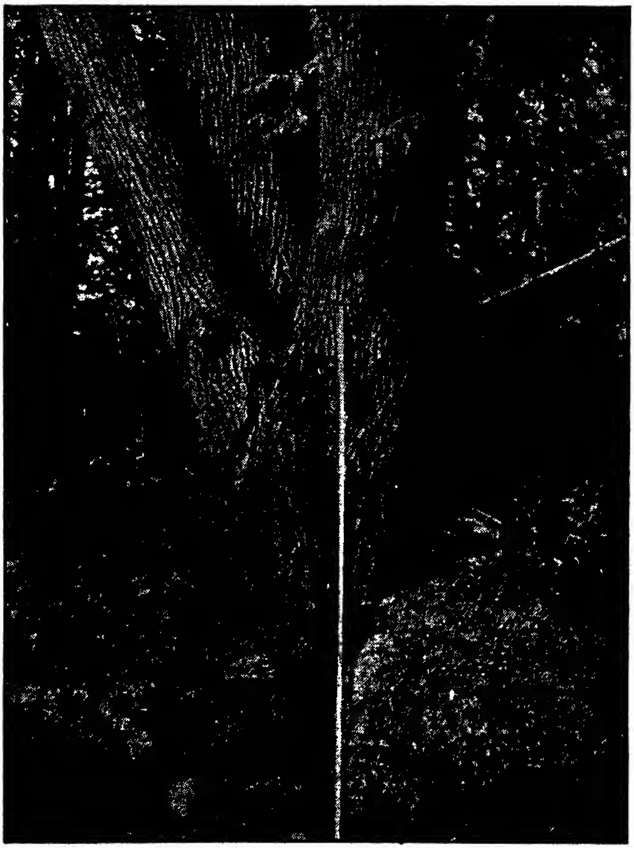

FIGURE 7. Trees sometimes find root in narrow cracks and assist in the process of weathering, breaking the rocks. (Vermont.)

the evergreen needles. Thus, under the northern evergreen forests, there is a thick mat of needles and twigs above the mineral soil, sometimes as much as 18 inches thick. In the southern pine forests, such deep mats do not develop; the needles decompose much too rapidly there where the temperature is high during most of the year. Under the broad-leafed trees the mat is thinner and the upper part of the mineral soil beneath the mat is darker and deeper because the decomposing organic matter has been mixed in it. Since the ground under the broad-leafed forest is not shaded during the winter and early spring, many flowering plants and small grass-like plants can grow.

Associated with these types of plants are other organisms. With the broad-leafed trees one finds many more earthworms and similar animals that assist in decomposing and mixing the organic matter than under the pines and spruces. With the acid, slowly decomposing plant remains under the evergreens there are more fungi than bacteria, as compared to the softer materials, relatively rich in minerals, left by native grasses. This is very important, because the fungi seem to produce rather soluable organic compounds that are easily leached from the soil,[1] while those produced by the decomposition of plant remains by bacteria are less soluble and tend to remain in the soil. Thus the well-drained soils developed under the pines and spruces of northern Maine are light in color while those developed under the tall grasses in southwestern Minnesota are black. This difference in color is not important for itself; but it indicates great differences in the processes through which the soils have developed and

[1] The fine clay and organic particles (colloids) are also moved down from the surface of these soils because of the acidity. See Chapter 9.

in their capabilities for use by the people who live on them. Not very much can be said about these differences in fungi and bacteria because little is known definitely. We do know that the proportions of different kinds of organisms in different soils are quite unlike and are partly responsible for differences among the soils as to fertility and structure, but much more study is needed before the details are known.

One special group of bacteria has been studied more than the others. These are the ones concerned with producing compounds of nitrogen that the plant can use. One group attacks the dead plant remains and transforms the nitrogen compounds in them to forms suitable for the growing plants. Once within the life cycle, nitrogen is used over and over again by living organisms. Other bacteria are able to take the relatively inactive nitrogen directly from the inexhaustible supply of the air and use it for their own growth. As the individual organisms die, this nitrogen can be used by plants also. Some of these nitrogen-fixing bacteria are called free-living, in contrast to others that grow only on the roots of certain plants—legumes, including clover, alfalfa, beans, peas, soybeans, and many others. For example, on many soils developed under trees in humid regions the farmer must add nitrogen to the soil as fertilizer to grow a good crop of corn, but if he grows clover or alfalfa before he grows the corn these bacteria will fix enough nitrogen from the air to reduce the need for such a fertilizer, or even make it unnecessary.

Since Roman times writers have urged farmers to plant more of the legumes—more clover and alfalfa—because they made soils more productive. Yet the reasons have been known for scarcely more than 60 years. Recently a

greatly renewed emphasis has been given the planting of these crops, especially in the humid portions of the United States. Not only do they take nitrogen from the air through the bacteria on their roots, but they make excellent hay and good pastures for livestock. At the same time they protect sloping soils from washing—soils that erode badly when used for crops cultivated in wide rows.

Speaking very generally, the native plants seem to produce chemical and physical changes that make the soil more productive for those plants. Pine trees tend to make the soil more productive for pine trees and grasses for grasses. Since most crop plants are similar to the grasses, we would expect the soils that have a native vegetation of grasses to be most fertile for them. This is true. Yet soils developed under a forest vegetation that may not be very fertile for crops under natural conditions may be made so by careful tillage, by adding certain compounds, such as lime, fertilizer, and organic matter to the soil, and especially by growing grasses and legumes at least part of the time. From the standpoint of the farmer the responsiveness of a soil to his care may be even more important than its natural fertility.

Climate, more than any other single factor, determines the kinds of plants in a place. But, of course, no single factor is completely responsible, any more than any single factor is responsible for a soil. The normal influence of climate may be changed by slope or drainage. The plants in the swamps are different from those in the surrounding well-drained land. Extremely sandy soils will have on them only certain plants that can grow under such conditions. Soils containing very large amounts of calcium carbonate may support grasses, even in humid regions with forests all about them. Near the boundary between

grasslands and forested regions, there may be forests on the north slopes of the hills and grass on the south.

Thus the kind of soil in any place is determined partly by the kinds of plants and, in turn, the kind of plants by the type of soil; and both are influenced by climate, slope, and the kinds of rocks. The vegetation is more changeable than the soil, yet if the vegetation changes the soil follows suit, in time. Soils with deep, nearly black surface horizons are formed in cool, subhumid regions under tall grass vegetation, as in northwestern Minnesota. In the same region and under the same conditions, except for forest instead of grasses, the soils are light-colored—nearly white in the upper part just underneath the surface mat of leaves and twigs. If the forest creeps over the dark-colored soil, replacing the grasses, it will be changed into a light-colored one. It will be made more acid. Much of the organic matter will be lost. If, for some reason, the grasses replace the forest, a dark-colored soil will begin to form.

Thus with a given vegetation on the land, in time the soil reaches an approximate state of equilibrium or balance with the parent rock, slope, and climate. New fresh minerals enter the soil from beneath just as fast as the rain washes material from the surface and leaches it out through the drainage. Sometimes such a soil is said to be mature. The soils in the lowland along streams are not mature; there has not been time enough for the soil building forces to change the freshly deposited materials as much as they will eventually. As long as fresh deposits are being added almost every year, a mature soil cannot develop. Yet these young soils may be very productive when properly cared for, as in the Nile valley, in the Mississippi delta, and in countless little valleys in hilly

regions. As the streams wear deeper into the earth, these soils become well drained and no longer subject to overflow by the stream. Grasses may grow and a black soil develop, or trees may produce a light colored soil. In the humid tropics, a deep red soil will be formed. All may come from the same kinds of rocks.

When land is cleared and planted to crops, the soil undergoes drastic changes, depending upon how different the new conditions are from the old. The natural balance is upset, or rather, perhaps, the near-balance, since nature is rarely, if ever, in perfect balance. The change may make the soil better or worse. When black soils developed under thick tall grasses are plowed and used for cultivated crops the amount of organic matter decreases and the soil becomes more compact, less spongy and porous. If such crops as corn, for example, are grown year after year the fertility may decrease a great deal and the soil become difficult to cultivate. If corn is grown one year, oats the next, and clover the third year it will decrease, but not so much. That is, the soil finds a new balance with the new vegetation. If the pine forest is removed from a light colored soil and grasses are grown much or all of the time, the content of organic matter in the soil will increase and the physical structure improve (Figure 75). As we shall see later, a change in vegetation from grasses or trees to cultivated crops like corn or cotton may cause more soil to wash away from the surface than under natural conditions. In such instances the farmer must plant close-growing crops instead or adopt practices like terracing or planting crops in strips to compensate for the effect of the natural cover in slowing down the water, or the soil will be lost. Well-watched terraces may reduce washing or erosion on sloping soils, but if they are neg-

lected they may only concentrate the washing in certain places and cause serious gulleys. Generally, however, best results may be had by growing the crops or combinations of crops best adapted to the soil conditions with as little use of special structures as possible.

Another important change brought about by the farmer is the harvesting of the crops. If the plants grown on the land are removed, the cycle of minerals from soil to plant and back to soil again is broken. Many soils have a great reserve of part or all of the plant nutrients, but frequently it is necessary to add one or more as fertilizer, in order to make up for those removed or to make the soil even more productive. The natural processes of erosion and soil formation, of course, bring new nutrients into the body of soils, and the processes of deposition, as along streams, add fresh minerals to other soils. If a farmer sells the crops directly more fertilizer will be needed than if he feeds the crops to livestock, returns the residues to the soil, and sells only the livestock or livestock products. Thus with the same soil, only lime and phosphorus may be needed on a livestock farm; while lime, phosphorus, potassium, and nitrogen may be required as fertilizer on a cash crop farm.

Of all the common crops grown the hay crops—grasses, clover, alfalfa, lespedeza, etc.—are generally least exhaustive to the soil. But even with these crops, fertilizers are frequently needed, and alfalfa especially may deplete the moisture stored in the lower soil. Grasses not only protect soils subject to washing, but their deep root systems tend to produce a good structural condition in the soil—tend to open it and make it more porous and sponge-like. Legumes like alfalfa have deep, strong roots and have the added advantage of harboring the bacteria that "fix" nitrogen. Only a few soils in the world will remain pro-

ductive unless they are often seeded to grasses—"laid down to grasses" as some people say. Many farmers in America have been growing too many cultivated crops and not enough of the grasses to maintain their soils in the best condition. Lately they have taken to growing many more of these grasses and fertilizing them with lime and phosphate with good results. Sometimes potassium and other elements must be added also.

For the present, more will not be said about this relationship between life and the soil. Only we must constantly remind ourselves that it is the dominant fact about soils. Like associations of plants, particular groups of animals find their best home on particular soils and, finally, man himself is a different creature on different soils.

4.

THE PARTS OF A SOIL

SOILS are made up of solid inorganic matter, dead organic matter, living organic matter (roots of living plants, small animals, bacteria, and fungi), water, soluble salts, and air. Each type of soil is made up not only of individual proportions of these things but, more important, of different arrangements of them—different patterns. As in a plant, it is not only the materials that help give it a distinctive character, but also the arrangement of these materials. Some soils may consist almost entirely of mineral matter like sand dunes or the nearly barren rocks upon which one finds the lichens, small green scale-like plants; others may be mostly organic matter like the peats and mucks of swampy places. Some may be nearly all water like the ponds where water lilies grow. Of course, most people haven't thought of lakes and ponds as soil at all. Nor do they regard the living trees on which other plants grow as soil, although one might, without stretching things too far. But the ordinary soils of the field and garden contain all of these things mixed together with by far the larger part made up of small mineral particles.

These mineral particles vary greatly in size, but ordinarily particles much larger than a grain of wheat or corn are not considered a part of the real soil, although pebbles, cobbles, and large stones may be found within the soil and on the surface. The proportion of the individ-

ual soil particles of various sizes is an important, relatively unchanging soil characteristic and is referred to as *texture*. Certain groups of particles have been defined according to size and called *separates* as follows:

Separate	*Size limits (diameter)* *Old system*	*New system*
Fine gravel	1.0 mm* to 2.0 mm	1.0 mm to 2.0 mm
Coarse sand	.5 " to 1.0 "	.5 " to 1.0 "
Medium sand	.25 " to .5 "	.25 " to .5 "
Fine sand	.10 " to .25 "	.10 " to .25 "
Very fine sand	.05 " to .10 "	.05 " to .10 "
Silt	.05 " to .005 "	.05 " to .002 "
Clay	Below .005	Below .002

* One millimeter (mm.) equals one thousandth of a meter or 0.03937 of an inch.

Since there are no sharp breaks, these size limits for each class are rather arbitrary, although most kinds of minerals in the soil begin to show the properties of clay at about .002 millimeters. As the size of the grains becomes smaller, the surface exposed per pound becomes larger. Below a diameter of .002 of a millimeter the surface exposed by a pound of soil grains becomes truly enormous. Four pounds of clay particles having diameters of about .001 millimeters would have a total surface of about one acre (Figure 8). Since many of the important properties of the soil, like the ability to hold water, and the chemical reactions, take place mostly on the surface of the soil grains, a given amount of clay has an enormously greater activity than the same weight of sand.

Of course, no soil consists wholly of any one of these separates. Only by mixing a soil with a large volume of water and separating out the grains of different sizes in the laboratory can one discover the exact proportions of them in any soil. According to the relative percentages of

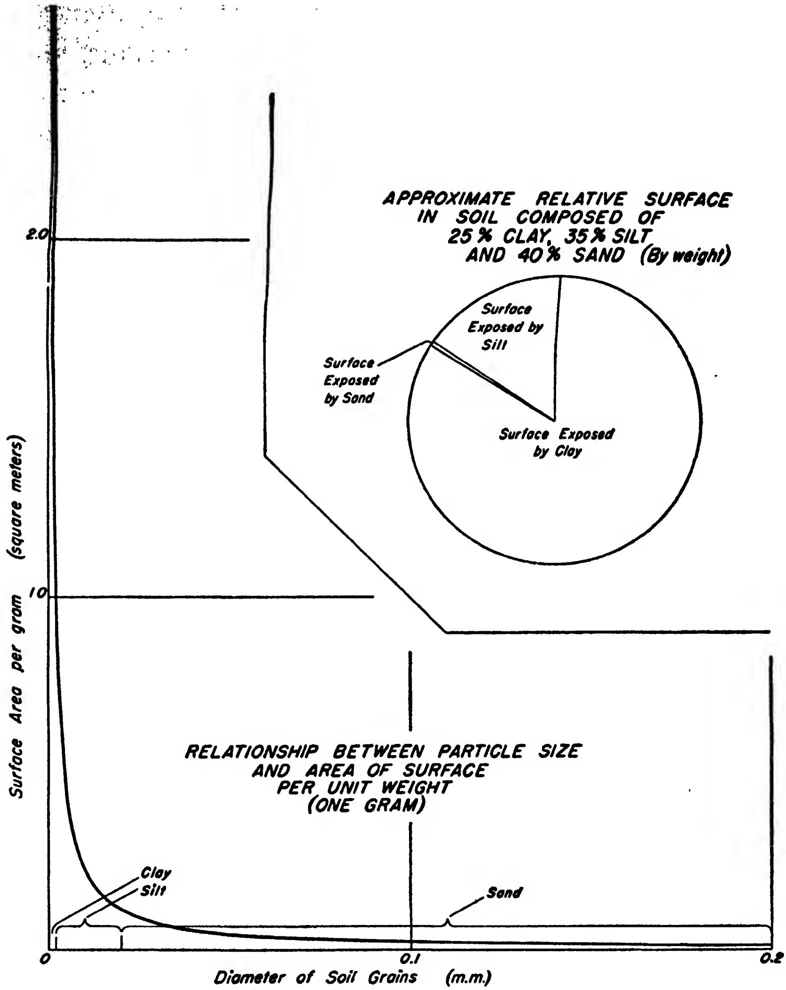

FIGURE 8. Drawings to illustrate the enormous increase in the surface exposed by a given weight of soil material with a decrease in the size of the individual particles. A relatively small amount of clay has a great influence upon the whole soil mass.

sand, silt, and clay in soil samples they are given *class* names. These may be modified according to the presence of fine or very fine sand, gravel, stones, chert, and cobbles. Thus we may have sandy loam and fine sandy loam, clay loam and cherty clay loam. A soil consisting almost wholly of sand is given the class name sand, and one consisting largely of clay is called a clay. Soils of intermediate textures are given class names as shown below, in increasing order of clay content. The most common modifiers are also shown on the right.

Sand	: Very fine, fine, coarse, gravelly, stony, or cobbly.
Loamy sand	: Very fine, fine, or coarse may modify sand; : and gravelly, stony, or cobbly may modify : loamy.
Sandy loam	: Very fine, fine, coarse, gravelly, stony, cobbly, : or cherty.
Loam	: Gravelly, cobbly, stony, cherty, shaly.
Silt loam	: Gravelly, cobbly, stony, cherty, shaly.
Silty clay loam	: Stony
Clay loam	: Gravelly, stony, cherty, shaly.
Silty clay	: Stony
Clay	: Sandy, stony.

The proper name of some place, like Miami, Barnes, Norfolk, or Hagerstown, plus the soil class name gives the name of a soil type. Thus in the soil type Barnes loam, the word "loam" refers to the texture of the surface soil while the name "Barnes" is a place name near the spot where the soil was first found. All soils with the name Barnes have a certain specific range in all characteristics, such as the color, depth, and structure of the several layers or horizons that make up the soil profile, slope, and stoniness. This part of the name is called the *soil series*

name. Many soil series have two or three types, according to the texture of the surface soil, such as Miami loam and Miami silt loam. For less important differences within the types, subtypes or *phases* are established such as Miami silt loam, sloping phase, or Barnes loam, stony phase, or Hagerstown silt loam, eroded phase.

Only rarely does each grain of soil rest by itself, but rather are these particles grouped into clusters or aggregates of different size and shape. Soil *structure* refers to this grouping of the individual particles into larger pieces. Sometimes the soil has no structure, that is, each grain is by itself as in loose sand, or they all cling together in large irregular masses. In the first instance the soil is said to be *single grain* and in the latter *massive*. There are four principal types of soil structure as follows:

1. *Platy*. The soil particles are grouped into relatively thin horizontal plates.

2. *Prismatic*. The soil particles are grouped into vertical, elongated blocky pieces or prisms. When the tops of these are rounded the name *columnar* is used instead. These prisms may be 1/4 of an inch to 6 inches in diameter.

3. *Blocky*. The soil particles are grouped into blocky pieces with relatively smooth faces and relatively sharp or only slightly rounded edges. These pieces may be about 1/8 of an inch to over 3 inches in diameter. Sometimes this is called *nut-like* or *nut* structure, especially when the angles are rounded.

4. *Granular*. More or less rounded aggregates. When the aggregates are very porous and irregular in shape the name *crumb* is used. These may be very small or over 1/2 of an inch in diameter.

Aggregates of any of these types can vary a great deal in

hardness and average size. Any one soil may have one or more horizons with different types of structure; indeed, it is even possible to find soils with all four main types of structure in four different horizons. If the separate aggregates—plates, prisms, blocks, or granules—are distinct and clearly separated from one another, the soil horizon is said to have well-developed structure. If they are not clearly expressed the soil is said to have poorly developed structure; and if there are no visible aggregates at all the soil is said to be structureless, either *single grain* or *massive*.

The best structure for growing crops is a granular or crumb structure, or at least one with aggregates that are friable, easily crushed with the hand or penetrated by roots. As a matter of fact, one of the principal objects of careful soil management must be the production and maintenance of a crumb structure through proper tillage practices and proper rotation of crops. Good structure in most soils can be maintained only through the occasional growing of grasses. The surface of soils subject to blowing, however, like many of those in the drier parts of the country, should always contain a large percentage of medium-hard clods that will protect the fine material from the force of the wind.

Whereas texture is a more or less fixed property of any soil, structure is variable, although each natural soil horizon shows an individual kind of variation. It changes with wetting and drying and can be altered by plowing and stirring. Soils that have well-developed structure when nearly dry may seem hardly to have any structure at all when wet, because as the fine clay particles are wetted they swell and the cracks in the soil are closed.

When the soil dries again the clay shrinks. Everyone who has seen a mud puddle dry up and the clay crack into irregular patterns has noticed this phenomenon.

Along with structure are other important physical qualities of the soil. One of these is consistence, which refers to the relative attraction of soil particles for one another, the ability of the soil to resist breaking, or the extent to which the soil may be molded without breaking. Consistence depends upon structure, texture, the chemical nature of the clay particles, and the moisture content. It may be thought of in reference to individual soil structural pieces, or to a soil horizon as a whole. Soils with crumb structure are called mellow. Many soils with a platy, blocky, or prismatic structure are easily friable to a crumb or crumb-like structure. Others may be hard when dry and plastic or sticky when wet.

Associated with both texture and structure is pore space or porosity. These spaces may be large, as in coarse, sandy soils, or those between large well-developed structural aggregates. In fine clays, or with dense aggregates the pores may be very small—too small for root hairs or micro-organisms, and even too small for the movement of water as a liquid. In most ordinary soils, about 40 to 60 percent of the whole mass is pore space, with the spaces filled with air and water.

Of course, the greater the pore space the lighter the soil in weight,[1] since there is not a great deal of difference in the actual specific gravity of the mineral material, which is about 2.65. That is, most mineral soil material is about 2.65 times as heavy as water. With ordinary

[1] The reader will note that "light" soils are actually heavier in weight, in pounds per cubic foot, than "heavy" soils. As commonly used, "light" and "heavy" refer to the draft of the plow. Clay soils usually are harder to plow than sandy soils, hence "heavier" to plow.

soils a layer one inch deep and covering an acre weighs about 110 to 225 tons, not counting the weight of any water it may contain. For organic soils—Bog soils or peats and mucks—these values may be as low as 10 or over 100. It is ordinarily assumed that one acre of surface soil to a depth of 6⅔ inches weighs 1000 tons or 2,000,000 pounds. Unfortunately this figure is widely used in attempting to determine the pounds of plant nutrients, total or available, per acre of surface soil from chemical data. The figure is only very, very roughly approximate. That is, by assuming this figure it may appear that two soils have the same amounts of available phosphorus, let us say, per acre of surface soil, when one may have twice as much as the other on an actual volume basis, since with one soil the real figure is not 1000 tons but 1500, and in the other perhaps 750.

Usually the higher the content of clay, the more plastic and sticky the soil when wet, the harder the blocks or prisms when dry, and the greater the difficulty of getting a structure suitable for crops. But this is only approximately true, because much depends upon the chemical characteristics of the clay. Many clay soils in the tropics, exposed to the severe weathering of a hot, moist climate, are not very active and the structure is easily maintained in a proper state so that water enters the soil very easily, and roots as well. Even many of the clay and clay loam soils of more northern regions have a high amount of absorbed calcium on the colloids and are in good structural condition, especially in the subhumid to arid regions.

One of the great enemies of good soil structure is cultivation. Although tillage may make a good structure temporarily, its effect may be to reduce the amount of true granulation or crumb structure. If prisms, blocks, or

FIGURE 9. This picture illustrates one of the most common and most important effects of accelerated soil erosion on farm crops in the region of podzolic soils. Here the friable, mellow surface horizons have been removed and the new surface soil must be developed by tillage from the heavier less friable B horizon. Because of the poor structure the soil is poorly aerated, roots cannot develop properly, and plants quickly suffer from drought. These spots of weak yellowish plants are common

large masses of soil are simply broken and pulverized, as soon as the soil is wetted thoroughly it will "run together" into these forms again—or more likely into an even more massive condition. Tillage implements, like the plow and the harrow, tend to shear and crush the granules and crumbs, especially if the land is plowed at times when the soil is very dry or very wet. If acid silt loams, clay loams, and clays of United States are plowed

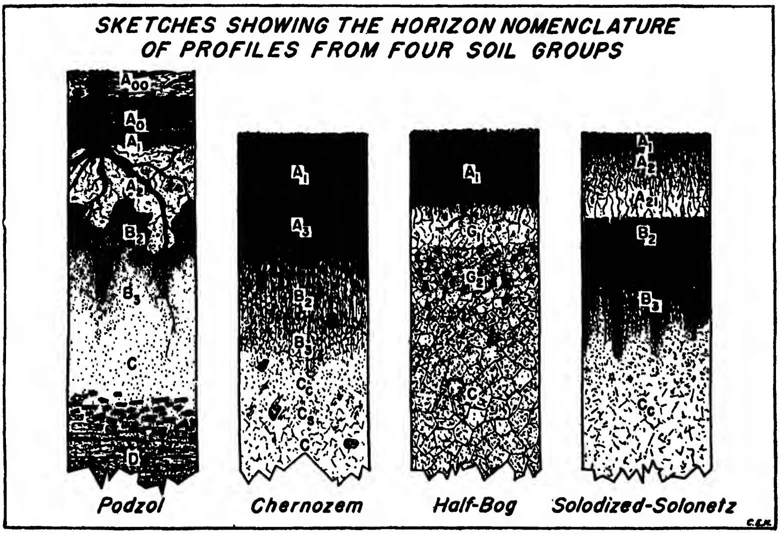

FIGURE 10. Four sketches showing how the nomenclature of soil horizons is applied to actual soil profiles. It will be noted that the boundaries between horizons may be smooth or very irregular and sharp or gradational. Compare with sketch in figure 12.

when very wet, most of them will have their structure ruined; and in many cases it may take 10 years of very careful treatment to recover a structure in which plants can grow well, even though the soil is fertile.

In much of the United States, the greatest harm from

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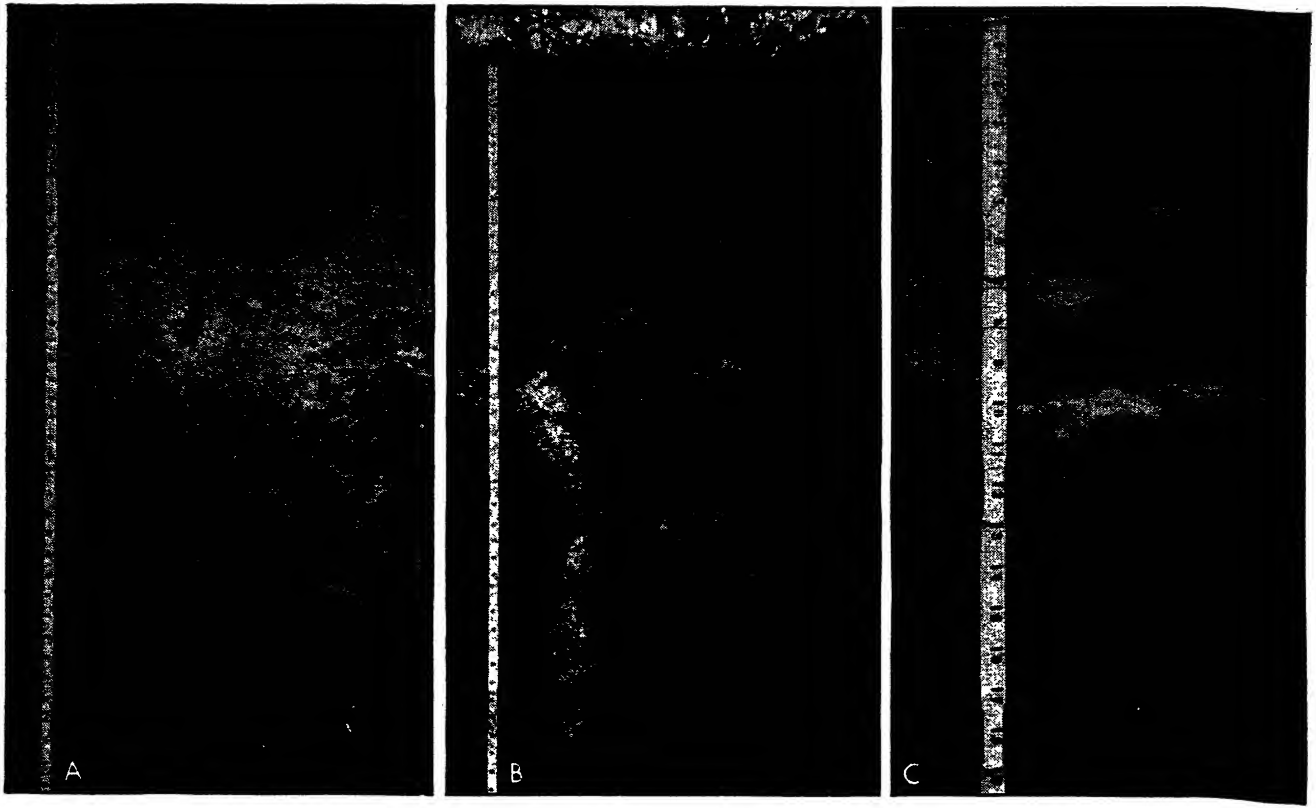
on hilltops where erosion may have been active. (Gray-Brown Podzolic soil developed from loess overlying limestone in southwestern Wisconsin.)


A
B
C

excessive soil erosion is the removal of a surface soil of good structure and the exposure of a lower horizon of poor structure (see Figure 9). Without any doubt this is much more harmful, especially in the eastern one-third of the country, than any chemical losses, although the two effects go hand in hand. The subsoil of many soils is so lacking in granulation—is so massive, especially when exposed at the surface—that it is almost impossible, by any practical means, to produce a seed bed suitable for crop plants.

It has already been mentioned that a soil is made up of several layers or horizons called collectively the soil profile. Sketches of soil profiles are shown in Figure 10 and photographs in several figures, including 11, 24, and 36. In Figure 12 is shown an idealized soil profile with all the possible principal horizons. No soil in nature has all these horizons, but every soil has at least some of them. The profile of a soil results from the combined influence of all the past events in its history. The anatomy or morphology of the soil is expressed by a complete description of the texture, structure, and other characteristics of the several horizons, and their thickness and depth, in the soil profile; just as the anatomy or morphology of an ani-

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FIGURE 11. Photographs of three soil profiles. (A) Podzol profile developed from heavy glacial till in northern Minnesota. The surface layers of leaf mold have been largely destroyed by fire. The acid, gray, A_2 horizon gives way to a dark brown B horizon at about 20 inches. Note the well-developed blocky or angular nut structure of this horizon. Although of heavy clay it is quite readily penetrable by roots. Note the filtration of "silica flour," along the cracks, into the B horizon. (B) A moderately well-developed Planosol profile developed on smooth relief from weathered limestone in Tennessee. The surface is yellowish-brown, friable soil to a depth of about 11 inches. The B horizon is reddish-brown heavy clay, plastic when wet and hard when dry, with a coarse blocky structure. (C) A solodized-Solonetz soil in southern California. Note the nearly white, leached, platy A_2 horizon. The clay soil of the B horizon breaks into hard columns, made up of jointed blocks.

Organic debris lodged on the soil, usually absent on soils developed from grasses.

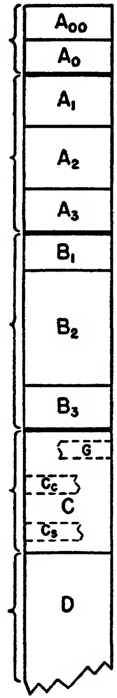
The SOLUM
(This portion includes the true soil, developed by soil-building processes.)

Zone of eluviation (of removal of materials dissolved or suspended in water).

Zone of illuviation (of accumulation of suspended material from A, as in podzolic soils). (Exclusive of carbonates or sulphates; in Chernozem, Brown soils and Sierozem this horizon is considered as essentially transitional between A and C.)

The weathered parent material. Occasionally absent i.e., soil building may follow weathering such that no weathered material that is not included in the solum is found between B and D.

Any stratum underneath the soil, such as hard rock or layers of clay or sand that are not parent material but which may have significance to the overlying soil.



Loose leaves and organic debris, largely undecomposed.

Organic debris partially decomposed or matted; frequently divided into subhorizons.

A dark colored horizon, containing a relatively high content of organic matter, but mixed with mineral matter. A thick horizon in Chernozem and very thin in Podzol.

A light colored horizon, representing the region of maximum leaching (or reduction) where podzolized or solodized. The "bleicherde" of the Podzol. Absent in Chernozem, Brown soils, Sierozem and some others.

Transitional to B, but more like A than B. Sometimes absent.

Transitional to B but more like B than A. Sometimes absent.

A usually deeper colored horizon, representing the region of maximum illuviation where podzolized or solodized. The "orstein" of the Podzol and the "clay-pan" of the solodized-Solonetz. In Chernozem, Brown soils, and Sierozem this region has definite structural character, frequently prismatic, but does not have much if any illuviated materials and represents a transition between A and C. Frequently absent in the intrazonal soils of the humid regions.

Transitional to C.

Horizon G represents the glei horizon of the intrazonal soils of the humid region, usually between A and C.

(Horizons lettered C_c and C_s represent possible layers of accumulated calcium carbonate or calcium sulphate found in Chernozem and other soils. Commonly, but not always, C_c is between B and C.)

Underlying stratum.

NOTES:
1. Important subdivisions of the main horizons are conveniently indicated by extra numerals, thus: A_{21} and A_{22} represent subhorizons within A_2, G_1 and G_2 subhorizons within G, etc.
2. Boundaries between horizons may be sharp or indistinct, smooth or irregular.
3. In some soils genetic horizons cannot be determined without laboratory study.

mal or plant would be expressed by a description of its forms and structures.' Any profound study of a soil or any general scheme for classifying soils must begin with this morphology.

These "parts" of a soil are called its internal characteristics. In addition, it is recognized that each soil has certain external characteristics of climate, slope, and stoniness.

Starting with freshly weathered rock or parent material, the soil gradually acquires a characteristic morphology, depending upon the kind of parent material, native vegetation, climate, and relief. Then a soil may go through a gradual change from a simple mass of rock fragments to a highly complicated body with a well-developed profile made up of distinctive horizons almost entirely unlike the original rock material. These processes of change are called processes of soil formation, or better still, processes of soil genesis (see Figure 13).

Some idea of the differences among the profiles of ordinary soils may be seen from the graphs shown in Figure 14. These show how the clay content, amount of organic matter, of silica (SiO_2), sesquioxides (Fe_2O_3 and Al_2O_3), and total bases (MgO, CaO, Na_2O, and K_2O), and the reaction vary under ordinary conditions. These soils will be discussed in following chapters and each is described in Appendix II.

The chemical examination of a moist soil, as found in the field or garden, shows that a large part of the mineral

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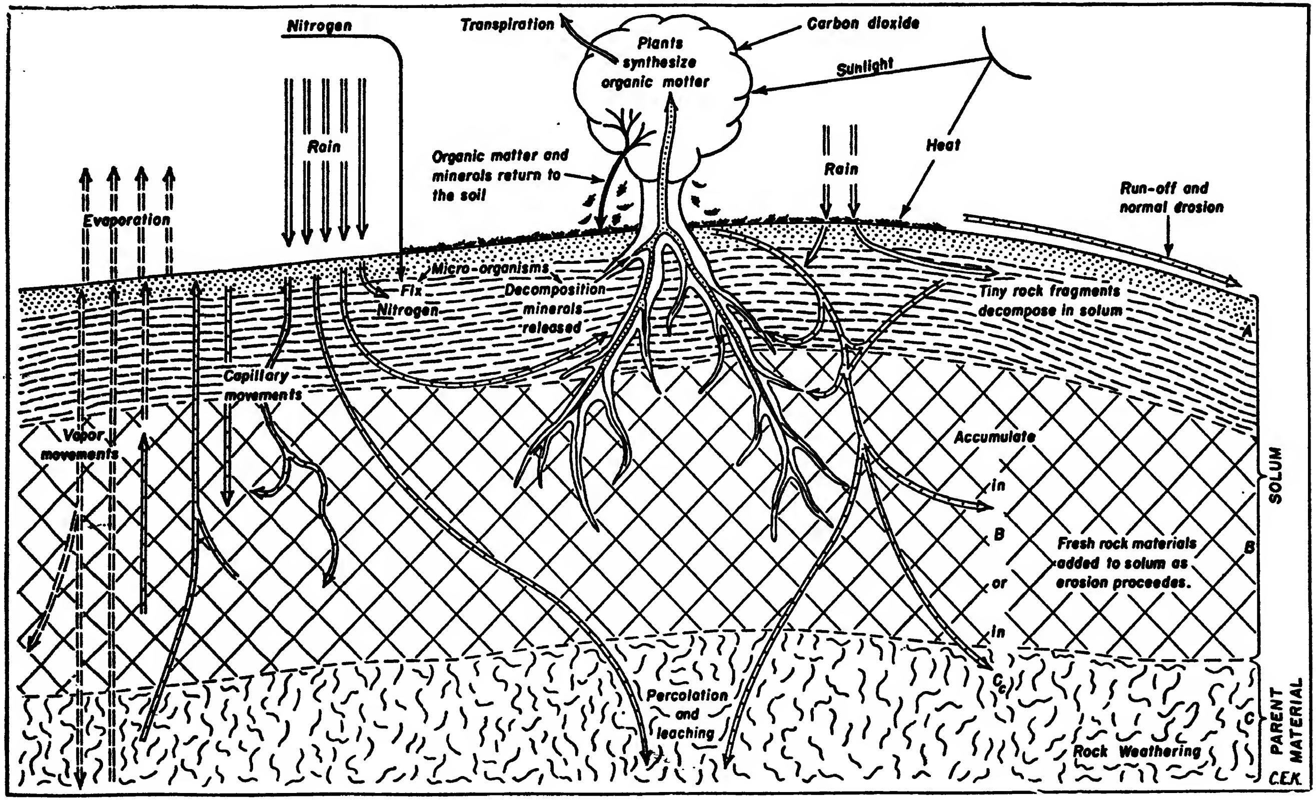
FIGURE 12. A drawing to illustrate the relative position of the various genetic soil horizons of soil profiles and their nomenclature. Of course, no soil would have all of these, but every soil has part of them. It will be noted that the B horizon may or may not have an accumulation of clay and that the C_c horizon (zone of calcium carbonate accumulation) may be between B and C or within the C.


Nitrogen
Transpiration
Carbon dioxide
Plants synthesize organic matter
Sunlight
Rain
Heat
Organic matter and minerals return to the soil
Rain
Run-off and normal erosion
Evaporation
Micro-organisms
Fix Nitrogen
Decomposition minerals released
Tiny rock fragments decompose in solum
A
Capillary movements
Vapor movements
Accumulate in B or in C_c
SOLUM
Fresh rock materials added to solum as erosion proceeds.
B
Percolation and leaching
C
PARENT MATERIAL
Rock Weathering
C.E.K.

matter is insoluble in water, while a small portion, the more active part in relation both to the plant and to the soil itself, is soluble. There is no sharp line separating these two portions of the soil, except that a more or less arbitrary one is chosen. Much depends upon the amount of moisture in the soil and how much carbon dioxide (CO_2) is dissolved in it. If much water is added, more material will be found in the soluble portion than if little water is used. Repeated leachings will increase still further the soluble portion. Thus the nature of the soil provides that only a small part of the potentially soluble material goes into solution at one time, but is replenished as plants remove a portion. In turn, the plants finally return at least a part of what they have taken, and through gradual erosion the soil profile, although remaining con-

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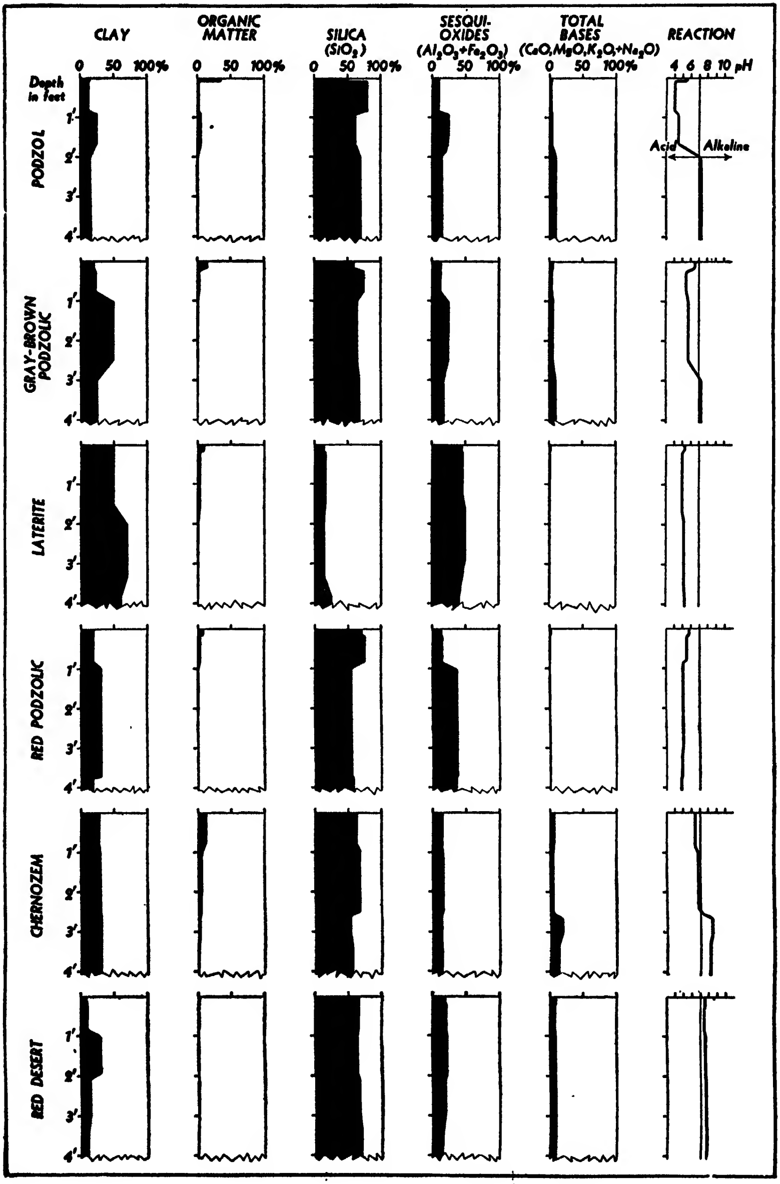
FIGURE 13. In this diagram are illustrated many of the main processes going on in a normal soil. The plants remove nutrients and water from the whole soil. With these and the carbon dioxide from the air, under the influence of sunlight, organic materials are produced. These materials ultimately return to the soil, on or near the surface. Micro-organisms decompose these to form humus and release the minerals and nitrogen to the soil again. Other micro-organisms can remove nitrogen from the air and fix it in forms that plants may use.

Rains come. A portion of the water enters the soil and passes through the pore spaces, carrying soluble materials (and sometimes fine clay or colloid particles) downward. At times there is enough rainfall for a portion of the water to percolate through the soil into the rocks beneath, along with any soluble materials in it. During periods without rain, water moves upward as a vapor and as a liquid in the capillaries. Water moving in the soil as capillary water, as in a lamp wick, carries soluble materials with it, whereas water vapor is essentially pure water. As water enters the pore spaces air leaves, and as it leaves fresh air returns.

Some of the water runs off, carrying some surface soil. As the surface is thus gradually removed by surface erosion, the whole soil sinks into the rock beneath and fresh minerals are brought into the solum, or true soil. These gradually decompose, releasing minerals for plant growth.

Thus in a normal soil many physical, chemical, and biological activities are going on all the time, each influencing the others and influenced by them.



CLAY
ORGANIC MATTER
SILICA (SiO_2)
SESQUI-OXIDES ($Al_2O_3+Fe_2O_3$)
TOTAL BASES (CaO, MgO, K_2O+Na_2O)
REACTION
0 50 100%
4 6 8 10 pH
Depth in feet
1' 2' 3' 4'
Acid
Alkaline
PODZOL
GRAY-BROWN PODZOLIC
LATERITE
RED PODZOLIC
CHERNOZEM
RED DESERT

stant in depth, is extended downward, bringing a fresh supply into its body. Such a mechanism for maintaining a small replenishable supply of soluble material is absolutely essential to plant life. The total quantity must not be too great or too small. But few plants will thrive in soils having more than 10 percent by weight of readily soluble material, while most crop plants require soils having less than one-half of one percent. Normal soils of normal productivity in humid regions have even lower contents of water soluble materials.

The soluble material in solution is constantly changing in total quantity and in the relative proportions of the various compounds. Plants reduce the amounts of certain compounds like phosphorus and available nitrogen during periods of active growth. In rainy seasons leaching may reduce the entire amount of soluble ma-

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FIGURE 14. Simplified diagrams showing the reaction and the amounts of several important substances in the profiles of virgin soils representative of six important great soil groups. Other individual members of each group will vary in clay content, and in other respects, with differences in parent material. The differences within any one profile shown here are due to the processes of soil formation acting upon the weathered parent materials. Soils from other parent materials, in each group, show similar kinds of differences.

Several fundamental differences may be noted. For example, the Podzol and other podzolic soils show marked accumulations of clay, and of alumina and iron oxide, in the B horizons, due mainly to movement from the A horizons above. The concentration of clay in the B horizon of the Red Desert soil is thought to be due mainly to greater clay formation in that horizon, which most of the time is more moist than the soil above or below it.

Although the clay content is about the same throughout the Chernozem, the bases, and especially calcium carbonate, are concentrated in the lime zone.

In the forested soils the content of organic matter is high in the very surface, but there is much more in the solum of the Chernozem.

Several other constituents are not shown and may make up quite a bit of the total weight of soil, such as water of crystallization and titanium oxide in the Laterite, inorganic carbon and oxygen in the carbonate ($CaCO_3$) of the Chernozem, et cetera. Of course, the silica (SiO_2) includes that in other minerals as well as quartz.

terials. If plants are not being grown but micro-organisms are plentiful and active, the amount of nitrates may be greatly increased. Further, the soil solution, as well as the material in the solid state, is highly heterogeneous, especially when the soil is at a normal or below normal moisture content. There are marked differences, of course, not only among the several horizons of a soil profile, but also between different points within a horizon. In one place a rootlet is giving off carbon dioxide and removing certain phosphate compounds, for example; in another place a clump of organic matter is decaying with the production of ammonia or nitrates; elsewhere potassium is being released from a particle of orthoclase; and so on throughout an almost infinite list of important reactions, necessarily taking place in a soil. Thus a plant does not grow normally in a uniform or homogeneous medium but in one so heterogeneous that practically every rootlet finds itself in a different medium from that of every other one.

The elements, of course, do not occur as such in the soil solution. Although there are some soluble organic materials and other molecules in solution the bulk of the soluble materials is thought to be present as *ions,*[2] such as the anions, carbonate (CO_3) bicarbonate (HCO_3), sulphate (SO_4), chloride (Cl), nitrate (NO_3), nitrite (NO_2),

[2] For this discussion we may think of an ion as an electrically charged atom or group of atoms in solution. Pure water is a poor conductor of electricity but if some salt, like common table salt, is added it becomes a good conductor. The current is carried by the Na-ion and the Cl-ion as the salt NaCl splits into these two parts in water. One atom, the Cl, gains an electron, while the Na loses one. These separate particles that carry the current are also called electrolytes and, by an extension of meaning, any substance that gives ions when dissolved in water is an electrolyte. If we pass an electric current through the salty water, the Na-ions will move to the negative pole, while the Cl-ions will move toward the positive. Those that move to the positive pole, or anode, are called anions, while those that move to the negative pole, or cathode, are called cations.

phosphate (PO_4), and hydroxyl (OH) and the cations, potassium (K), ammonium (NH_4), calcium (Ca), sodium (Na), magnesium (Mg), and hydrogen (H). Largely through their roots, plants absorb water and ions. In addition some organic materials may enter the roots, possibly with importance to the growth of plants. The anions and cations apparently enter the plant root in pairs, or rather in chemical equivalents. As they become depleted others come into the soil solution by the solution of minerals, from decomposing organic matter, and from the colloids.[3]

The relative proportions of hydrogen (H) and hydroxyl (OH) ions have special significance as the determining factor of soil reaction (acidity or alkalinity). When water solutions have the same amount of each they are neutral; when the hydrogen predominates the solutions are acid; and an excess of hydroxyl ions produces alkalinity. Acidity and alkalinity are expressed in numbers as *pH*. A pH of 7.0 indicates precise neutrality, higher values alkalinity, and lower values acidity.[4]

The solubility of various minerals and the growth of many organisms is greatly influenced by the concentration of hydrogen ions. Water in which carbon dioxide is dissolved is a weak acid. Other acids, such as nitric, sulphuric, and organic acids are produced in the decomposition of organic matter. Certain other substances in the soil, such as calcium carbonate, frequently present in the parent material, and also produced by the decomposition of organic matter and the carbonation of the ash, tend to produce a predominance of hydroxyl ions, or an alkaline reaction. Most (but not all) crop plants find the soils

[3] See glossary.

[4] See *reaction* in glossary for approximate values of different degrees of acidity expressed in words and in pH.

most favorable for their growth near the neutral point, between about pH 6.2 and 7.5. Several plants, however, like cranberries, strawberries, and rhododendrons, require a more acid soil, and a few a more alkaline one, but very few will grow in soils having a pH less than 3.5 (extremely acid) or greater than 9.0 (very strongly alkaline).

With changes in reaction a whole group of other changes in the soil take place. On the alkaline side iron, manganese, magnesium, and several other substances are relatively insoluble. The silica is more soluble than on the acid side. With a very high pH the organic matter dissolves and because of the high concentration of OH ions the soil colloids are likely to be highly active. On the acid side iron, alumina, and many other substances become more soluble. These soluble iron and alumina compounds may then combine with the phosphates and form insoluble compounds. Acid soils are almost universally low in phosphorus, and phosphate fertilizers frequently become insoluble when supplied to the soil.

Soil organisms do not thrive when the soil is highly alkaline. Those bacteria most active in the decomposition of organic matter and the production of nitrates thrive best between about pH 6.2 and 7.5. As the pH decreases and the soil becomes acid the fungi increase at the expense of the bacteria.

Especially under intensive management a great deal of attention must be given to the pH of the soil and to the balance among the several active substances used by plants. For example, a naturally highly acid soil may need an addition of lime in order to raise the pH and create a favorable reaction for the growth of plants. Only a very small amount of lime would be needed to neutralize the soluble acidity but the bulk of the soil acids are rela-

tively insoluble organic, silicic, and alumino-silicic acids (hydrogen-colloids), which act as buffers and oppose any sudden changes in pH. For this reason soils high in colloids, organic or inorganic, require more lime for a given change in pH than soils low in colloids. If soils have been formed under extremely acid conditions and with considerable leaching, the content of iron, magnesium, and manganese, for example, may be extremely low. As soon as the pH is raised by the addition of lime the solubility of the little that remains may be so reduced that an extreme deficiency develops unless the proper fertilizers are added also. Again a nitrogen fertilizer may be added to a soil relatively low in one or several of the other plant nutrients, giving rise to such an unbalanced condition that plants grow abnormally with increased susceptibility to disease.

The material in solution influences and is influenced by the solid particles, especially the clay. The fine portion of the soil particles, both organic and mineral, is called colloidal. Such material does not form a true solution in water, like salt or sugar, but under proper conditions forms a more or less stable suspension in water, as in quiet muddy water. Each individual particle is larger than a single molecule but too small to be seen with the naked eye. Formerly, it was thought that these particles were not crystalline, but now it is known that many soil colloids are tiny crystals of different minerals. With different rocks, different kinds of weathering, and especially different types of soil formation, different kinds of colloids are formed in the soil. Most of the mineral colloids are some kind of alumino-silicate, produced by the partial weathering of minerals. The organic colloids in the soil come from the decomposition of organic matter.

Although these tiny colloidal particles do not enter the plant roots, except possibly to a very small extent, they greatly influence the ability of the soil to hold plant nutrients and water, and to furnish them to growing plants. Someone has aptly called this colloidal material the "protoplasm of the soil."

Some colloids are more active than others, as we shall see, depending upon their chemical composition. If treated with some electrolyte such as calcium chloride or aluminum sulphate (used in water purification plants) suspensions of soil colloids are flocculated (attracted into small clusters or soft granules and settled out). On the other hand, additions of ammonia or sodium hydroxide (strong lye) tend to disperse them, throw them into suspension. If the colloids are flocculated, the soil has a crumb or crumblike structure. When dispersed the soil is plastic or sticky and dries into a hard mass.

These colloids can absorb ions, and then release them again in exchange for other ions. The more of any particular ion, like the hydrogen-ion, or the calcium-ion, in the soil solution, the more that ion will be absorbed by the colloid. Then, if the solution becomes low in this ion it will return again from the colloid to the solution. Thus an ion in the solution may exchange for one in the colloid. This is called ionic-exchange or more popularly, base exchange.

If hydrogen is the dominating ion in the colloid, the soil mass is acid and the individual particles are rather easily dispersed in salt-free water. On the other hand, if calcium is the dominating ion in the colloid, the soil mass is mildly alkaline and, in most soils, the particles are not easily dispersed but tend to remain in clumps or clusters. But if sodium is the dominating ion, the soils are very

strongly alkaline and the colloids are very easily dispersed in ordinary water. Of course, any of them are flocculated if salts are added to the water. The amount required depends upon the salt; a great deal of sodium chloride would be required to be as effective as a small amount of calcium chloride, or even a still smaller quantity of aluminum sulphate.

Thus the hydrogen-colloids and the sodium-colloids can be leached, or moved from one part of the soil to another by water. Most soils developed under forests in humid regions become acid in the surface and the hydrogen-colloids do move from the A to the B horizons and these soils have, therefore, more clay in the B horizon, or subsoil, than in the A horizon, or surface soil. The colloids of most soils developed under grasses in semiarid regions, on the other hand, are largely of the calcium type and are not easily moved. Thus in such soils, even when fully developed, there is not much difference in the clay content of the several horizons.

Streams in limestone country are usually clear and sparkling because the colloids are not easily dispersed. In the dry regions, the soil may contain many sodium-colloids and the water is frequently alkaline. Here the streams may be very muddy, like the Missouri. This name is from the Indian language and means "big muddy" in ours. Also in dry regions especially, there may be so much soft calcium carbonate, calcium sulphate, or other salts in the soil that the colloids are flocculated in small soft crumbs that are easily carried away by running water. Usually soils with much calcium-colloid have a granular structure and are so pervious to water that there is not much run-off or erosion. But if the soils are too highly flocculated they may be very erosive indeed, es-

pecially if the lower horizons are relatively impervious to water.

Years ago many people who studied soils studied only the surface soil, that part moved during plowing and cultivation. Now it is known that such studies are not nearly enough since the roots of plants extend deep into the soil and get water and nutrients from the lower horizons as well. A soil may be strongly acid in the surface, for example, but require little or no lime for clover because the lower layers are neutral. Tests of the surface soil alone may be very misleading. Further, the ease with which water passes through the soil or is held for growing plants between rains (or applications of irrigation water) depends upon the nature of all the horizons, not simply those at the surface. Two soils may have quite similar surface horizons yet one have permeable horizons underneath into which roots may penetrate and through which water may pass, while the other has a dense massive horizon beneath through which neither roots nor water can pass. If the second soil is sloping, it will erode easily if barren of vegetation because as soon as the surface soil is soaked with water it will flow down the hill, while the excess water can pass through the lower horizon of the first soil and drain out. Thus some gently sloping soils erode readily while other soils do not erode easily, even on steep slopes.

5.

THE RAINS COME AND GO

WATER is necessary to all living matter. Soils have the property of holding water so that plants may have what they need. A good soil allows the rain to enter freely, allows the excess water to drain away, and holds enough for growing plants between rains. Indeed, on all the land in the world being used for crops, water is most commonly the cause of low yields. There is either too much or too little at some time while the crops are growing. Above all, we must remember that almost all soils are made up of layers, or horizons, and commonly these different layers are very unlike. Perhaps a soil is loose and open to water for 10, 20, or 40 inches and then there is a dense layer only a few inches thick, but thick enough to make drainage very slow or stop it altogether. The appearance of the surface often tells us little about what is underneath. Although some soils are given extra water through irrigation this is a costly practice and, except in the drier regions, most soils receive only such water as falls in the rain and snow.

When water falls, all or part of it sinks into the soil; the remainder flows off. This portion is called the *run-off*. Of that which sinks into the soil, a part may go completely through and down to a hard stratum or to a water table, a few feet or several hundred feet beneath the surface, carrying dissolved matter with it. It may strike a

layer of hard rock and flow along the surface and come out of the ground at a lower level as a spring or in a "seepy" spot. This water that flows through the soil is called water of *percolation.* Of that which does not pass through the soil or flow off the surface, some is lost back to the air by *evaporation,* and some passes through the growing plants and is lost from their leaves by *transpiration.* In the formation of an ideal productive soil, some of the water should escape in each of these four ways, not too much or too little in any one way.

Water lost through run-off carries with it some of the soil material from the surface. Under natural conditions with the normal vegetation this may be a very small amount in any one year, even though the whole landscape may be lowered many feet during thousands of years. But this small amount is necessary. As this tiny bit is removed, the soil profile moves down just a tiny bit. Thus a little of the soil at the top is replaced by that just underneath and fresh minerals enter the soil body from beneath. This is one of the most important dynamic processes included in soil formation, especially in regions where there is a lot of rainfall. It is one of the ways by which soils, both in forest and field, keep productive.

Where there is much rainfall, that is, as much as in Illinois or Virginia, or more, and the soil is nearly level, there may be too little run-off and too little natural erosion to remove material from the surface. Unless the soil material is quite sandy, a dense clay layer or hardpan is likely to form in the lower part as a strongly leached horizon develops above it; and no new minerals are added to the lower part of the soil. Indeed, roots may not even be able to get to the lower part at all. Some nearly level silty soils are poor for crops because of too little run-off

while they were being formed. A large part of the so-called "worn out" soils of eastern United States are of this kind—they never were fertile for crop plants, not even "when the Indians had them."

If there is too much run-off, too little water enters the soil. Plants do not grow vigorously and soil formation goes slowly. Also erosion proceeds too rapidly. Because of the small amount of water for plants and because of the greater erosion, the soils are thinner than normal. It has been said that on steep slopes soil erosion proceeds more rapidly than soil formation. This does happen sometimes for a short time, especially when the vegetation is removed. But it is not true in the natural landscape; otherwise, of course, there would be no soil at all. Excess run-off is most common where the plant growth is weak or thin, as in the desert or on barren, sloping fields. Even soils that had too little erosion under natural conditions may have too much when kept bare or in cultivated crops a great deal. If erosion goes very far, these soils will be made even poorer by exposure at the surface of the clay-pan or hardpan underneath. Thus, one of the many things that the farmer and the forester must guard against is too much run-off. But more of that later.

Like run-off, some percolation is a good thing, too much is a bad thing. Most plants will not grow well if there is very much salt in the soil. There must be, of course, some soluble material, but not too much. Certain native plants, like many of the low desert shrubs, will endure a fairly large amount of salt, but most crop plants cannot. If there is some water percolating through the soil enough of the very soluble materials are washed out to keep them from accumulating in harmful amounts. On the other hand, if there is a great deal of percolation,

the soil becomes too leached of plant nutrients, especially those, like the nitrates, that exist as very soluble compounds. Thus in eastern United States, if the sandy soils are exposed to the fall rains without some crop growing to use up part of the water and absorb nutrients from the soil, these may be leached out and lost. Rather than leaving the soil barren, oats, rye, or other crops may be planted in the autumn as cover crops. On sandy soils these crops take up part of the water and absorb nutrients that may be returned to the soil again in the spring plowing. On the sloping soils they reduce run-off and erosion.

Evaporation of water takes heat. When water is evaporated from the warm soil, it is cooled. This is also one of the effects when plants give off water from their leaves. (And the reason why streets are sprinkled during hot days.) The direct rays of the sun on the soil, when barren or having widely spaced plants, would make it very hot—too hot for the normal growth of plant roots and micro-organisms—were it not for this cooling effect of evaporation. Indeed, in tropical countries many soils cannot be exposed openly to the sun for long periods without damaging the micro-organisms, because of a lack of sufficient water for cooling the surface. To what extent this may be important in the United States is not known. The more the evaporation, of course, the less water there is left for plants. When covered with dense vegetation there is less direct loss of water from the soil in this way. Sometimes the soil between plants is even covered with paper to prevent evaporation (and weed growth), especially in growing pineapples.

The loss of water from the soil by transpiration through plants is ordinarily what is wanted, not for its own sake, but because the purpose of agriculture and forestry is to

grow plants that require water. It is necessary to guard against the loss of water through unwanted plants—weeds. The greatest harm of weeds is their stealing of water from the other plants. For a long time people have known that the cultivation often saved or conserved the water in the soil. At one time many thought this was due to the making of a sort of "dust mulch" on the top. Now we know that the biggest advantage is in killing weeds, although making the surface more receptive so the rain water may penetrate the soil more easily is also very important.

From all this, it is plain that water is always moving in and out of any ordinary soil. And there is always water in the soil. The less water in the soil, the more strongly the soil holds what remains. Even when the soil gets so dry that plants wilt and die from lack of water, there is still some water there. This may be as little as 1 pound for each 100 pounds of absolutely dry soil in very sandy soils, or as much as 30 pounds per 100 pounds in heavy clay horizons of certain soils. This water that plants cannot

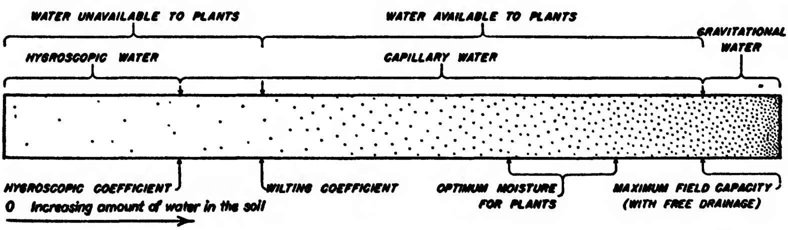


FIGURE 15. The relationship of the different forms of water in a soil, beginning with absolutely dry soil at the left and becoming increasingly moist to the right. The range of optimum moisture for ordinary crop plants is well up in the scale of capillary water, although they will grow with lower amounts present. Desert plants, other plants in a resting stage, and micro-organisms can use some of the water below the wilting coefficient as ordinarily defined. If the amounts are increased beyond the optimum, plants are likely to suffer from lack of air, even though this superfluous water is, in a sense, available.

get is held by the soil very tightly on the surface of the particles and a little in the tiny pores. That held on the surfaces is called hygroscopic water. It does not move freely, even as vapor, and does not dissolve salts as ordinary water does, or freeze at the same temperature as plain water (see Figure 15).

As more water is added to a dry soil, it is held in the fine pores and as loose films around the soil grains, like the oil in a lamp wick or the water in a wet blanket hung up to dry. This water is called capillary water, because the soil holds water somewhat like a bundle of twisted, uneven fine glass tubes—capillary tubes. It is this water that plants use. As still more water is added to the soil, some drains through under the pull of gravity, like the extra water that may drip off the wet blanket. This extra water that percolates through the soil is called gravitational water. Ordinary plants cannot use it.

If a block of earth were removed from an ordinary soil it would be found that somewhere between 35 and 65 percent of the volume of it was taken up with solid matter. The rest, or about 35 to 65 percent, is pore space, filled with air or water. In an average soil, productive, let us say, for corn, and where there is just the right amount of rain, about one-half of this pore space is filled with water. These figures vary a great deal among different soils and even for different horizons in the same soil. Although sandy soils are said to be porous, the total pore space is greater in heavy clays, yet many of these are so fine that water can scarcely move through them. If the clay particles are grouped into granules or crumbs, many of the pores may be large and water will pass through the soil easily. In the tropics it is not uncommon for nearly all

of the water to sink into soils made up entirely of clay during the extremely heavy tropical showers; the excess passes immediately through into the deep drainage. Again the clay particles may have "run together" as in a mud puddle and, when dry, exist in great massive lumps or blocks. Except through occasional cracks, water can scarcely penetrate the mass. Rains may fall for hours and scarcely dampen the soil beneath the immediate surface while the greater part runs off.

In the desert and sometimes in barren soil elsewhere, a thin, brittle surface layer may form that allows scarcely any water to enter the soil, except during prolonged, gentle rains. Growing plants will do much to open up such soils, once they can be started. Of course, this cannot be done in the desert without irrigation. In the dry regions, near the desert, once the grass has been destroyed such a structural condition may develop that makes it difficult for water to enter the soil or for plants to get a foothold again, except during abnormally moist seasons.

Sandy soils almost always allow water to enter easily. Also they hold very little that is not available to plants. But they allow too much to drain away. During wet periods, plants may grow well on the sandy soils while they suffer from too much water (or rather too little air) on those high in clay. During normal seasons of good but not excessive rainfall, the soils with a fair amount of clay—the loams, silt loams, clay loams, and clays—will hold more water for plants. But then again in very dry years the sandy soils allow all the water to enter, roots penetrate them easily, and they hold little away from the plants. Thus from the standpoint of water, the sandy soils are best for plants in really wet years and extremely

dry years. It is for these reasons that trees for shelterbelts in the Great Plains do best on fairly sandy soils and poorly on the heavier soils.

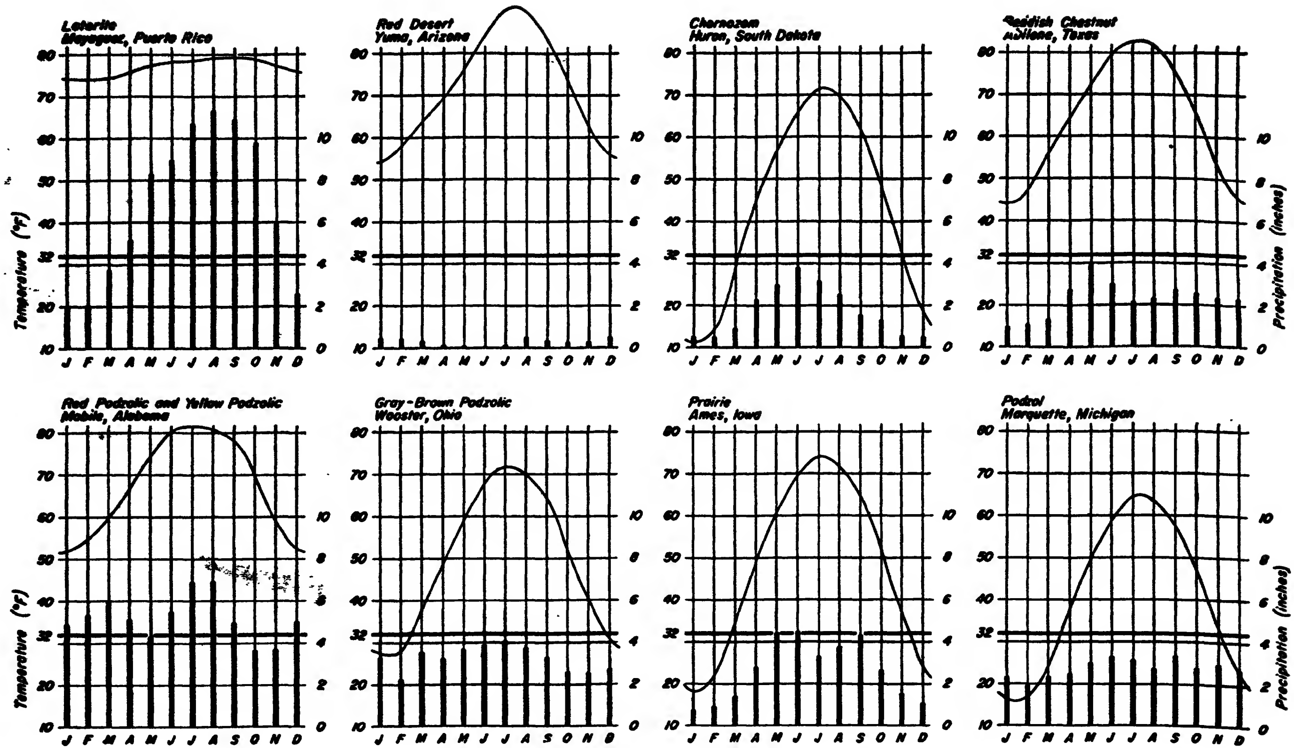
Water moves down in the soil through the pore spaces, either as a vapor or as ordinary liquid water. When it is drier at the surface than beneath it may move upward in either form. Water does not move sideways very much, except within a permeable or sandy layer lying over a hard layer of a sloping soil, or outward in a steep bank or cut. The pull of gravity is, of course, downward, and the wetting and drying take place at the surface so most of the movement is up or down. Although the pull of gravity is important, it is not nearly so important as most people suppose except for the gravitational water, that left over after the capillaries will hold no more. When water falls as rain or is added by irrigation it enters the pores or capillaries and is pulled by those with little water from those with much water or, one may say, pushed from those with much to those with little. The same action is shown by the spreading of a drop of ink on a blotter. This can be shown very easily by placing fine sand in large tubes having a coarse screen in the bottom to hold the sand, and adding water from the top. Water collects in the sand near the bottom of the tube before any begins to drip out, just as it hangs in the bottom of a fine glass tube when it is removed from a dish of water. If the large tube is one-half filled with sand, then a layer of pebbles is added, and finally the tube is completely filled with sand, excess water will accumulate just above the pebbles also, because the capillaries are broken there as they are at the bottom.

Thus when the surface of the soil is moistened by rain or irrigation, the water moves down into the drier soil by

the force of gravity and especially by capillary movement in the pore spaces. During periods without rain, if the surface becomes much drier than the soil beneath, water will move upward, against the pull of gravity, by the same capillary action—from moist soil to dry soil. The distance or height that water can move depends upon the size of the pore spaces and whether or not they remain about the same size. In well packed very fine sand or silt, with little clay, water will move up to the surface from several feet. When there is much clay, the soil swells when moistened and shuts off the fine capillaries. In coarse sand the pores are very large and the water will rise little.

If the water in the lower soil is salty, these salts will be brought to the surface and left there as the water evaporates into the air. In arid regions salty water from the surrounding land may seep into a shallow water table only a few feet beneath the surface of the soil, and crusts of salt may be formed on the surface by this process (Figure 31). The water may move upward some distance in the soil by capillary action and the rest of the way to the surface as vapor, thus producing a layer of salt within the soil. Even in humid regions, there is usually a very slight accumulation of salt on the surface when the soil is dry, sometimes enough to be seen as a very faint white film.

As the surface of the soil freezes, ice crystals form that pull water out of the fine pores and set up a movement of capillary or film water. Just after a hard freeze, one may notice the ice crystals under boards or slabs of stone left lying on the ground. As the water comes up it freezes, and more moves in to take its place. As ice crystals form at the surface in cold weather there is a steady upward movement of water as long as there is moisture in the


Laterite
Mayaguez, Puerto Rico
Red Desert
Yuma, Arizona
Chernozem
Huron, South Dakota
Reddish Chestnut
Abilene, Texas
Red Podzolic and Yellow Podzolic
Mobile, Alabama
Gray-Brown Podzolic
Wooster, Ohio
Prairie
Ames, Iowa
Podzol
Marquette, Michigan
Temperature (°F)
Precipitation (inches)
J F M A M J J A S O N D

lower soil. In the northern part of the country this process often causes severe damage to concrete pavements. Where pavements are built over very fine sands or silts with a water table only a few feet below, huge blocks of ice may form under the pavement in this way, heaving it and breaking it. The action can be prevented by placing a layer of stones beneath the pavement in order to break the capillary connections, like the layer of gravel in the tube of sand. Formation of ice in this way often heaves plants out of the ground, especially in the spring when there is much freezing and thawing. Also at the margins of gulleys or other breaks in the surface, ice crystals may loosen the soil and cause it to move down the slope. This action of freezing and thawing helps produce a crumb structure and where there is little danger of serious erosion farmers plow very heavy soils in the autumn and leave them exposed during the winter.

Water also moves within the soil as a vapor. In ordinary soil, the air is saturated with water vapor. If the air above is dry, this vapor moves into the dry air. More water passes into vapor and thus out of the soil. The amount of water that the air can hold depends upon the temperature: warm air can hold a great deal, cold air only a little. But even cold air below zero can hold some water, and in dry regions much water may pass from snow or ice directly into the cold, dry air. In cold air the pressure of water vapor is low and in warm air high. If the surface of the soil is very cold and the lower part warm,

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FIGURE 16. Graphs showing the average monthly rainfall and temperatures at stations with long records in several important zonal soil regions. A heavy horizontal line indicates the freezing point. Note that the rainfall on Chernozem and Prairie soil falls especially during periods when the temperature is well above the freezing point and evaporation is high. Frequently there is a dry season in the region of Laterite soils.

water vapor moves from the warm part to the cold part in order to equalize this pressure. But as soon as it gets to the cold part it either moves into dry air above or settles out as ice; then more comes. Thus, added to the capillary movement of water upward when the ground freezes, is this vapor movement. Almost no matter how dry a soil may be before freezing, it is invariably moist in the surface when it thaws. In instances where there may be little or no capillary movement, this loss of water vapor may be quite important. Much water may be lost from soils during cold winters when there is no protective covering of snow. In North Dakota, for example, where the air in winter is often very cold and dry, the soil may become very dry if there is no covering of snow. Such losses of water are sometimes very serious because they rob the spring wheat crop.

All of these movements of water into the soil, along the surface, and within the soil are greatly influenced by the climate, slope, and vegetation as well as by the nature of

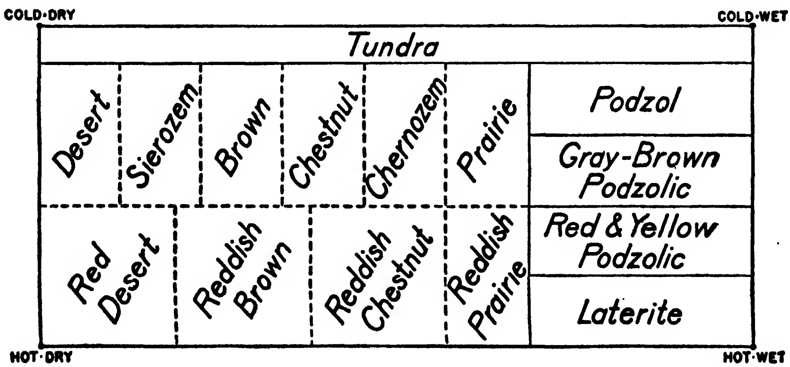


FIGURE 17. A somewhat oversimplified sketch showing the relative position of the more important zonal soils on an ideal smooth great land surface. Actually all continental areas are broken by mountains that interrupt the smooth land surface and influence climatic patterns and life zones.

the soil horizons and the underlying rock. With low rainfall there is little water to enter the soil. With high temperatures and dry air there is much evaporation. The average monthly rainfall and temperatures for several places within different soil regions are shown in Figure 16. After the discussion of these soils in subsequent chapters it might be well to return to this figure. An oversimplified sketch in Figure 17 shows how the regions of the great soil groups might lie in respect to one another were there no differences in the rocks or in slope and elevation.

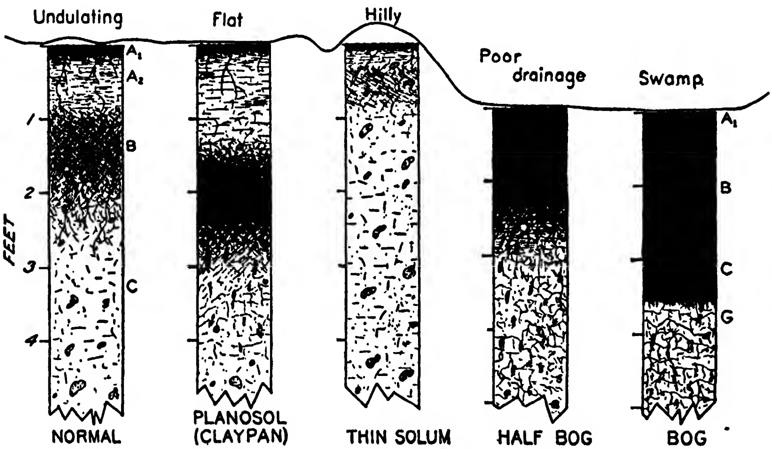


FIGURE 18. Sketches of five soil profiles developed over similar parent materials but with varying surface relief in the region of Gray-Brown Podzolic soils. Reading from left to right are: (1) The normal soil develops under conditions of good drainage and normal run-off. (2) The soil with a claypan (Planosol) develops on flat uplands with imperfect drainage, very slow run-off, and less than normal erosion. (3) The soil with a thin solum develops where run-off is great and the energy of soil formation less than normal. (4) The soil with a dark, mucky surface develops under a swamp forest where drainage is poor. (5) The Bog soil develops under a swamp forest where drainage is poor and peat has accumulated to such an extent that the parent material of the soil is organic matter.

Such a group of different soils, developed in the same region from similar parent material, is called a catena.

The effects of climatic conditions are greatly modified by the soil. On steep slopes, the effective rainfall as far as plants and soil formation is concerned, is reduced because of the increased run-off. In low places there is more than the normal rainfall. These differences are reflected in the character of the soil (Figure 18). If the low places have poor underdrainage excess water may accumulate all or part of the time, giving rise to swamps in the humid regions and salty soils in the arid regions. If there is good underdrainage, the soil may be characteristic of a more humid region. In such places one may find Chernozem-like soils in the Chestnut soil regions of the Great Plains, similar to those of more humid regions 300 miles or more to the east. In basins or on flats with poor underdrainage and no regular drainage the water table may fluctuate a great deal. Part of the time the soil is too wet for the roots of plants and part of the time very dry. In the open bogs of the northern humid regions little shrubs, leather leaf and Labrador tea, grow. They can endure such extremes. Their leaves are arranged so that losses of water can be held to a minimum during dry periods. In this respect they are related to the plants of the desert, even though they grow in the bogs.

The run-off is greater on steep slopes, on barren soil, and when showers are sudden. More water will enter the soil ordinarily if it is covered with close growing plants. Generally speaking the soil that forms under any given type of native plants and climatic region is the one best suited to the plants and climatic conditions. For example, there is more water available to plants during drought in the black soils of central Nebraska than in light-colored soils of central New York, assuming the

same parent rock, the same slope, and the same rainfall during the particular season of drought.

Soils of semiarid regions must be able to store water for long periods, else plants will suffer from drought. In the great wheat-producing sections of the Great Plains and the Pacific northwest, usually not enough water enters the soil during the growing season for a good crop. In parts of the Great Plains many farmers do not even plant their wheat unless there is a good deal of stored moisture in the soil because they know there is small chance of enough rain to produce a crop during the growing season if the soil is very dry at planting time.

6.

SOILS OF LITTLE PLACES AND OF BIG PLACES

EVERYWHERE one may look at the soil, it will be different than the soil of any other place. No two snowflakes, or flowers, or animals, or soils are just exactly alike. The differences between any two soils may be very small or very great. Since any natural soil is the result of five factors—(1) climate, (2) vegetation, (3) parent rock, (4) slope, and (5) age—a difference in any one will make a different soil. To such differences must be added those caused by man—by his plowing, harvesting, and other work. Man may make soils better or worse than he finds them by his treatment. The soils of Europe are, on the whole, much improved by careful management. In America some are better and many are not so good as they were before the white men came.

In order to understand how the different soils may be best managed it is necessary to classify them.[1] For centuries people have been using soils and finding out what uses are best for them. What is a good use for one may be a very poor use for another. One man may find that crops grow better if he adds lime to his soil, but a neighbor may find that it does not change his, whereas on a third soil it may even cause an injury. The same may be said of almost any farm practice. Terraces may reduce

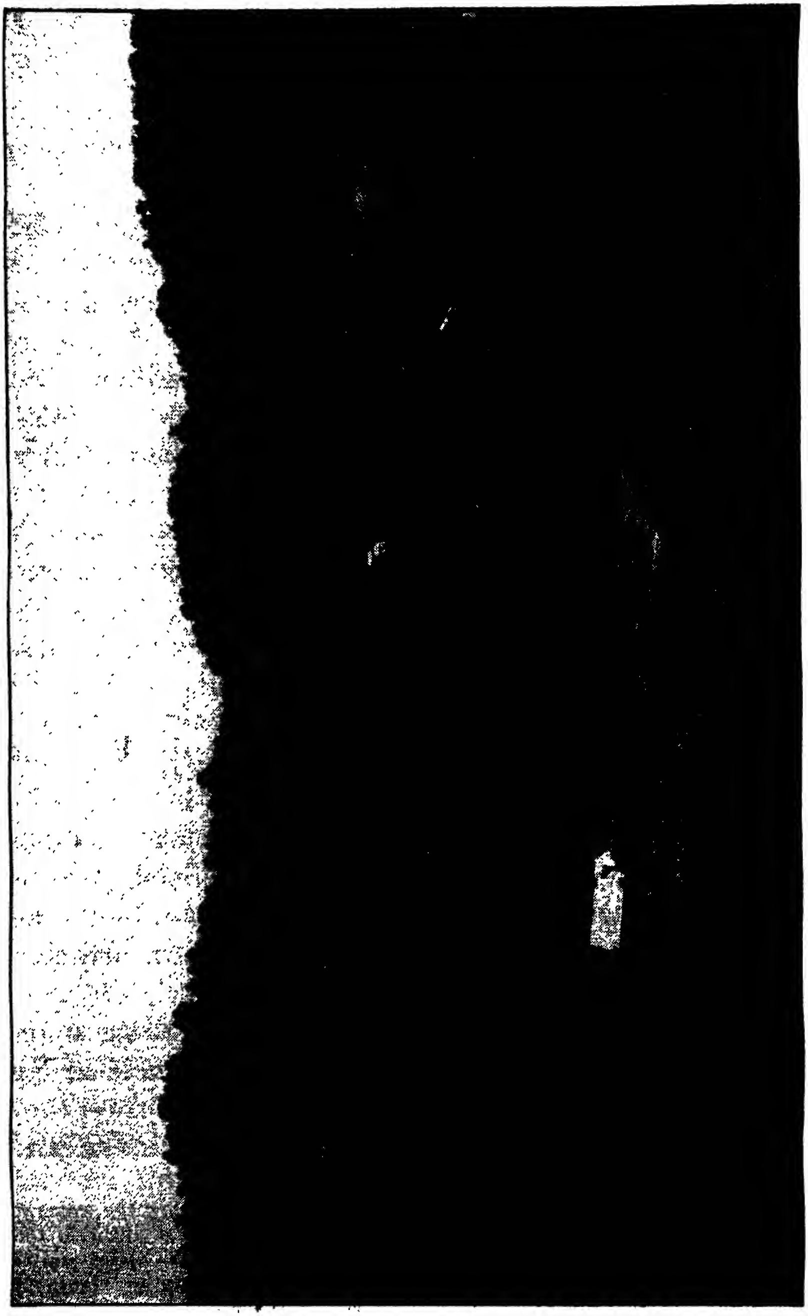
[1] See also Appendix I and II.

the amount of soil washed from sloping fields where the soil is permeable to water and yet may cause even more washing on others where the soil has a hard dense layer underneath.

Not only are there different degrees of differences between soils, but also different kinds of differences between them. First, there are those differences due to local variations in parent rock, slope, or age. These are the ones with which many of us are most familiar. Our garden is sandy but our neighbor's is a clay loam; one is nearly level, and the other is hilly; in one there are several different layers while in the other the soil is about the same from the top to several feet beneath; or one may be wet (and either mucky or salty) while the other is well drained (Figure 19). Secondly, there are those differences due to climate and vegetation. From the same rocks, on the same well drained gentle slopes, a soil in Maine is light colored and acid, one in North Dakota is black and neutral (neither acid nor alkaline), one in Arizona is light colored and alkaline, and one in the tropics is red and acid. Then, we might add, there are some soils so young that no new features have developed, such as the fresh material just deposited by a stream, or the almost bare slopes of the mountains, or the dry, nearly sterile sand along the beach.[2]

The most important groups of soils are those upon which the climate and vegetation have left their strong influence. These are called the *zonal* soils because they are found in great areas or zones in places where the land

[2] To the student there are available detailed maps showing the climatic conditions in the United States (see especially the Yearbook of the U.S. Department of Agriculture for 1941) and also geological maps of states and of the whole country. For general orientation the sketch map in Figure 20 shows the principal physical divisions of the United States.



is well drained and not too sloping, and on all kinds of parent rock except the extreme sands and extremely limy soft rocks, which have been in place under the natural vegetation for a long time. Different kinds of zonal soils are most regularly developed and most easily seen on great land masses, or continents. For this reason they are sometimes called the continental soil types or great soil groups.

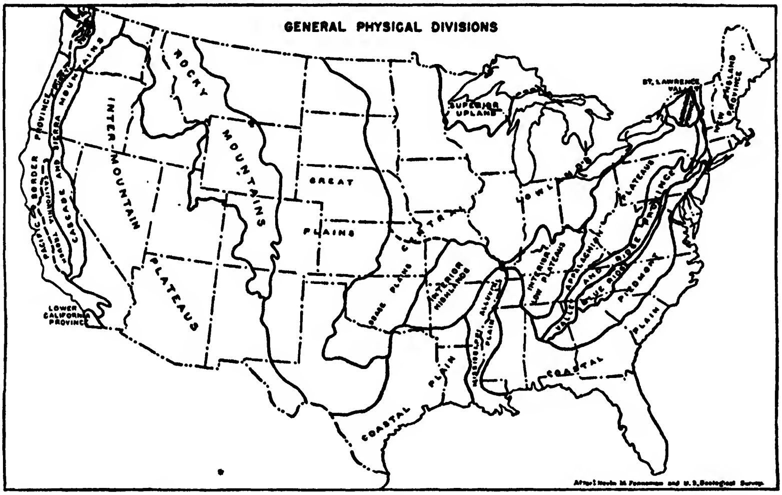


FIGURE 20. A generalized sketch of the principal physical divisions of the United States.

First, all zonal soils may be divided in two groups, (1) those of wooded regions, and (2) those of treeless regions. The four main types of zonal soil formation are represented by (1) the cool wooded regions, (2) the warm wooded regions, (3) the grassland regions, and (4) the desert regions. Thus there is one great group of zonal

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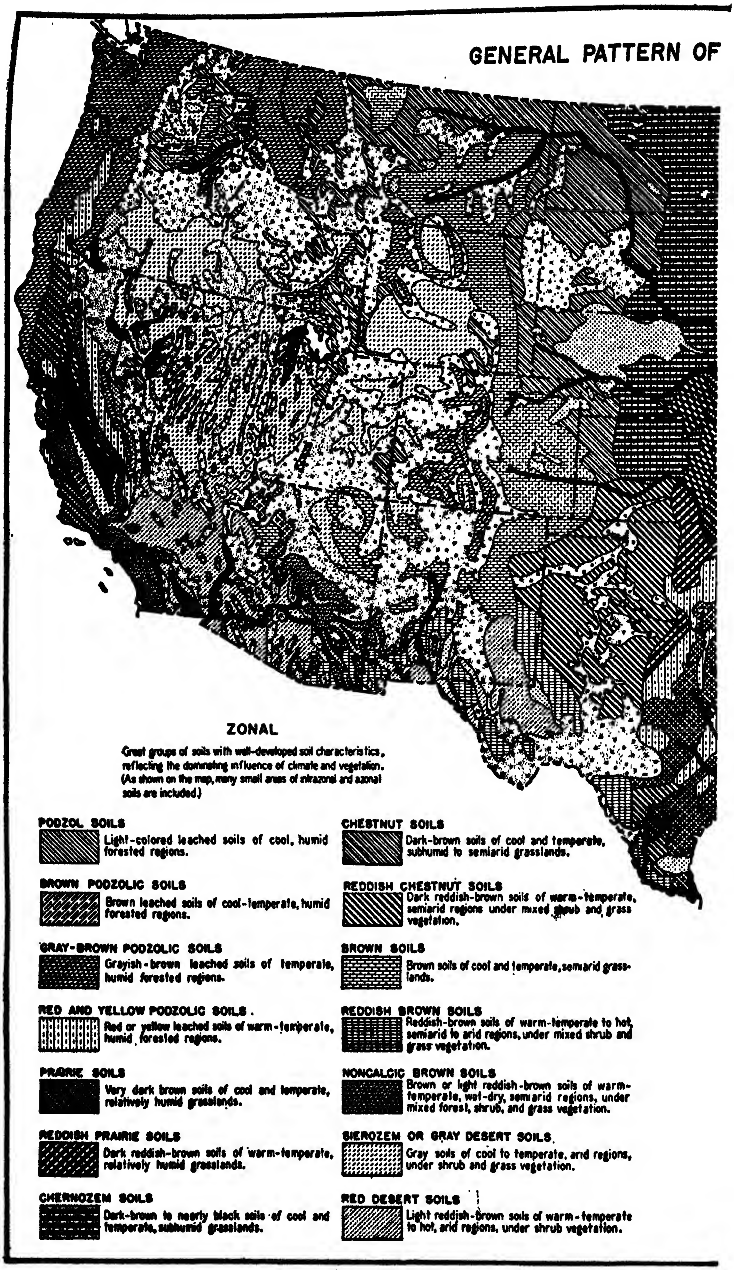
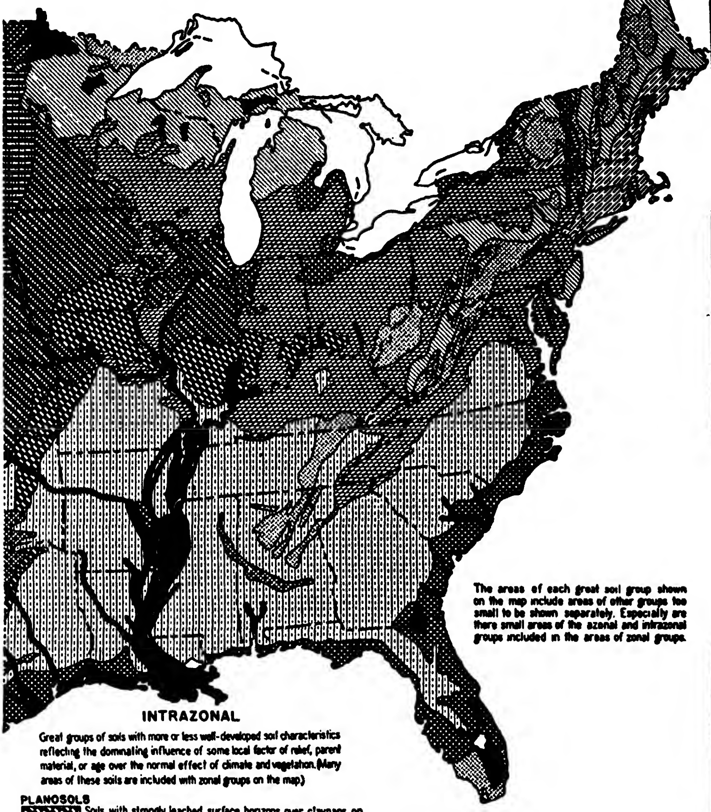
FIGURE 19. A characteristic view on the Red Podzolic soils of Tennessee developed from limestone. Note the complex pattern of slopes to which the farm layout must be carefully adjusted if the farm is to be successful over a long period.



GENERAL PATTERN OF
ZONAL
Great groups of soils with well-developed soil characteristics, reflecting the dominating influence of climate and vegetation. (As shown on the map, many small areas of intrazonal and azonal soils are included.)
PODZOL SOILS
Light-colored leached soils of cool, humid forested regions.
BROWN PODZOLIC SOILS
Brown leached soils of cool-temperate, humid forested regions.
GRAY-BROWN PODZOLIC SOILS
Grayish-brown leached soils of temperate, humid forested regions.
RED AND YELLOW PODZOLIC SOILS
Red or yellow leached soils of warm-temperate, humid forested regions.
PRAIRIE SOILS
Very dark brown soils of cool and temperate, relatively humid grasslands.
REDDISH PRAIRIE SOILS
Dark reddish-brown soils of warm-temperate, relatively humid grasslands.
CHERNOZEM SOILS
Dark-brown to nearly black soils of cool and temperate, subhumid grasslands.
CHESTNUT SOILS
Dark-brown soils of cool and temperate, subhumid to semiarid grasslands.
REDDISH CHESTNUT SOILS
Dark reddish-brown soils of warm-temperate, semiarid regions under mixed shrub and grass vegetation.
BROWN SOILS
Brown soils of cool and temperate, semiarid grasslands.
REDDISH BROWN SOILS
Reddish-brown soils of warm-temperate to hot, semiarid to arid regions, under mixed shrub and grass vegetation.
NONCALCIC BROWN SOILS
Brown or light reddish-brown soils of warm-temperate, wet-dry, semiarid regions, under mixed forest, shrub, and grass vegetation.
SIEROZEM OR GRAY DESERT SOILS
Gray soils of cool to temperate, arid regions, under shrub and grass vegetation.
RED DESERT SOILS
Light reddish-brown soils of warm-temperate to hot, arid regions, under shrub vegetation.

FIGURE 21.

GREAT SOIL GROUPS



The areas of each great soil group shown on the map include areas of other groups too small to be shown separately. Especially are there small areas of the azonal and intrazonal groups included in the areas of zonal groups.

INTRAZONAL

Great groups of soils with more or less well-developed soil characteristics reflecting the dominating influence of some local factor of relief, parent material, or age over the normal effect of climate and vegetation. (Many areas of these soils are included with zonal groups on the map.)

PLANOSOLS
Soils with strongly leached surface horizons over claypans on nearly flat land in cool to warm, humid to subhumid regions, under grass or forest vegetation.

RENDZINA SOILS
Dark grayish-brown to black soils developed from soft limy materials in cool to warm, humid to subhumid regions, mostly under grass vegetation.

SOLONCHAK (1) AND SOLONETZ (2) SOILS
(1) Light-colored soils with high concentration of soluble salts, in subhumid to arid regions, under salt-loving plants.
(2) Dark-colored soils with hard prismatic subsoils, usually strongly alkaline, in subhumid or semiarid regions under grass or shrub vegetation.

WIESENBÖDEN (1), GROUND WATER PODZOL (2), AND HALF-BOG SOILS (3)
(1) Dark-brown to black soils developed with poor drainage under grasses in humid and subhumid regions.
(2) Gray sandy soils with brown cemented sandy subsoils developed under forests from nearly level imperfectly drained sand in humid regions.
(3) Poorly drained, shallow, dark peaty or mucky soils underlain by gray mineral soil, in humid regions, under swamp-forests.

BOG SOILS
Poorly drained dark peat or muck soils underlain by peat, mostly in humid regions, under swamp or marsh types of vegetation.

AZONAL

Soils without well-developed soil characteristics. (Many areas of these soils are included with other groups on the map.)

LITHOSOLS AND SHALLOW SOILS
(ARID-SUBHUMID)
(HUMID)
Shallow soils consisting largely of an imperfectly weathered mass of rock fragments, largely but not exclusively on steep slopes.

SANDS (DRY)
Very sandy soils.

ALLUVIAL SOILS
Soils developing from recently deposited alluvium that have had little or no modification by processes of soil formation.

C.E.K.

soils called the *Podzols,*[3] found throughout the world under the evergreen trees or mixed evergreen and broad-leafed trees in cool, humid regions, as in northern Minnesota, northern Wisconsin, northern Michigan, Maine, Vermont, and New Hampshire. The *Laterite*[4] soils are found under a heavy tropical forest in hot humid countries. Another group, the *Chernozems,*[5] are found under the tall grass vegetation in temperate to cool subhumid regions, as in the eastern parts of South Dakota, North Dakota, and Nebraska, and the most western part of Minnesota. The *Desert* soils are developed in arid regions under a scanty shrub vegetation. There are several other zonal soils more or less in between these four principal ones.[6]

Although a great region may be dominated by Podzol soils there are many varieties of Podzols due to minor differences in climate, vegetation, parent rock, relief, and age. Beyond that, not all the soils in the Podzol region will even be Podzols. Those that have well-developed characteristics reflecting the influence of some local factor of relief or parent rock are called *intrazonal* soils, that is, they may be found within two or more soil zones. The most important of these are the Bog soils, commonly called peats and mucks, of the moist or humid regions,

[3] The word Podzol comes from the Russian language and means ash-like. The soils get their name from the nearly white or ashy-gray horizon (A_2) just beneath the thick surface layer of needles and leaves.

[4] This word comes from a Latin word for brick. For centuries the soil material in the lower part of one special kind of Laterite has been used in Indo-China, India, and elsewhere for making bricks (Figure 54).

[5] The word Chernozem comes from the Russian language and means black earth or black soil. These soils are black to a depth of one to three feet and have a layer of calcium carbonate within reach of the plant roots. This name is used in English because there are other kinds of black soils, like those in swamps, and on soft limy deposits in humid regions, that are entirely different.

[6] See the map in Figure 21 and the table in Appendix II.

and the salty soils of dry or arid regions. Usually these are found in small spots but if some special condition of poor drainage is widespread they may cover a large area, like the Dismal Swamp of Virginia or the Everglades of Florida in the forested regions, and the great salty flats of Death Valley and other treeless regions.

Other groups of intrazonal soils are those with nearly level surfaces and hard layers at one to three feet beneath the surface. There has been so little erosion, or washing away of the surface, that the acid leached material has all remained on the surface and a "hardpan" or "claypan" has formed underneath. Many of the poor infertile soils of eastern United States are of this kind. Some people have supposed that they are poor because of being farmed too much—"worn out." But they never were any better. General Washington had some of this kind of soil on his plantation at Mount Vernon and tried, without much success at that time, to find a way to make good crops grow on it. They are called *Planosols*—soils on a plain. But, of course, not all soils on a plain are of this kind.[7]

Besides the soils having characteristics developed by the climate and vegetation, as influenced by slope and parent rock, there are some that are so young that such characteristics have not had time to develop. These soils are called *azonal* because they may be found in any soil zone and their internal characteristics are largely due to the parent materials since they have not been changed by the forces of climate and vegetation. One kind of these soils is the Dry Sands, including moving dunes and those that have been covered with plants but are little changed. A very long time is required to make much change in this kind

[7] Other intrazonal soils are shown on the map in Figure 21 and described in the table in Appendix II.

of material. Another group are called *Lithosols*—rock soils; these are found on steep rocky slopes, as in high mountains. Not until the slopes have weathered down to the angle of repose, that is, to a slope gentle enough for the weathered rock to accumulate, can much soil form.

The *Alluvial* soils are the most important of the azonal soils. Many zonal and intrazonal soils can form from alluvium—the material that settles out of the water along streams and in deltas. True Alluvial soils, however, are those that are so young that no new soil characteristics have developed since the material was laid down by the water. They are found along stream margins in the flood plains and at the mouth of streams where floods leave new films of sediment each year or so. Their internal characteristics depend upon the material carried down by the stream. Rapidly flowing water will leave stones and gravel, more slowly moving water will drop sand and fine sand, and finally very slowly moving or still water will drop clay. Many of these soils are very fertile because they are getting fresh minerals added to the top each year, like those along the Nile or Mississippi rivers. Many of them need to be drained and protected from floods to be used for crops and those in desert regions need to be irrigated all or part of the time. Some are flooded for a few weeks or months but can be farmed during the rest of the year. In regions where there are many hills and valleys

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FIGURE 22. A small corn field on Alluvial soil in the southern extension of the region of Gray-Brown Podzolic soils. In many hill-valley areas the sloping soils may be used for pasture if there are soils adapted to corn for grain. These small areas become very important to the use of much larger areas. Since the upland soils are not suitable for corn, where they are not associated with these small patches of soil that are adapted to corn, farms cannot be developed and they can be used only for forestry. Thus any soil map of such a region must be very detailed to be useful in agriculture. (Western North Carolina.)

there are usually long slender, winding strips of these soils along both small and large streams (Figure 22). Many times they are the best soils the farmer has. After the stream has cut a deeper channel or changed its course so they are no longer flooded the soil gradually changes to the zonal soil of the region. Thus very similar Alluvial soils may change gradually, one to a Podzol, another to a Chernozem, a third to a Desert soil, and so on.

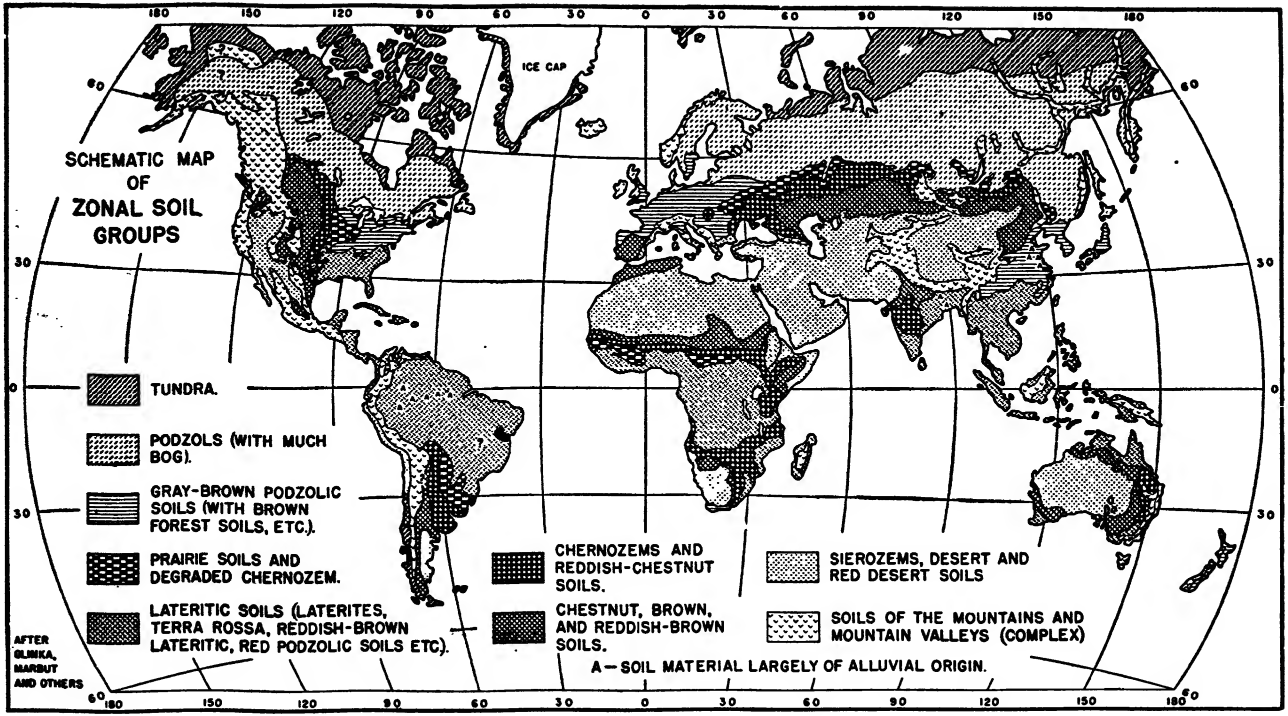
If we want to compare the soils of two big places—large areas like the northern Lake States and the eastern Great Plains—first we are concerned with the zonal groups: the former is Podzol and the latter Chernozem. As we think of small areas within these great regions, we will be concerned with families within the zonal soil and the kind and amount of the intrazonal and azonal soils. Then when we get down to thinking of farms or fields we will be concerned with local soil types, varieties within the great soil groups.

These local differences are expressed by *soil types.* Each soil type has the same layers or horizons, is developed from the same kind of rock, and has about the same slope, climate, and native vegetation. The first part of its name is the proper name of some lake, city, stream, or other feature near the place where it was first found, plus the name of the texture of the surface. Thus Miami silt loam, Barnes loam, and Norfolk fine sandy loam are names of local soil types. Some soil types are alike except for the texture of the surface soil such as Miami loam, Miami silt loam, and Miami clay loam. This group of three is called a series—the Miami series. In an ordinary county there may be 25 to 100 of these series with one to three types in each. And there are a great many, in some instances several hundred, series in one zonal soil group.

Each of these hundreds of soils has the same general profile, but each varies from the others in one or more ways that influence the use of the land, the practices which the farmer should use for best results, the kinds of crops that are best adapted to the soil, or the yield and quality of different crops.

When experiments are made to find out what soil treatments are best, the results can be applied only to the same kind of soil upon which the trials were conducted. Much effort and expense has been wasted by people who do not realize this fact. They see the good results of an experiment or of another farmer with a particular drainage system, with a certain fertilizer, with a kind of terrace, and then do the same thing on their own farm. Very often the practice that was so successful somewhere else fails completely on their farm because the soils were different in some important respect that they did not realize. Thousands and thousands of farmers, or would-be farmers, in our country have failed simply for this reason —by trying to farm one soil by methods that will produce results only on another kind of soil.

Within soil types there are sometimes variations that do not influence the native plants, or the formation of the soil under natural conditions, but are important in using the soil for crops. For example, every soil type has its own range in slope. For some this is very narrow—they are always nearly flat, for example, or gently sloping, strongly sloping, hilly, or steep. Others may have the same characteristics except that part is gently sloping and part is strongly sloping, for example. The part least common is separated from the rest as a subtype and called a *phase*. Thus within soil types there are phases for any important differences in slope, degree of erosion, stoni-


SCHEMATIC MAP OF ZONAL SOIL GROUPS
ICE CAP
TUNDRA.
PODZOLS (WITH MUCH BOG).
GRAY-BROWN PODZOLIC SOILS (WITH BROWN FOREST SOILS, ETC.).
PRAIRIE SOILS AND DEGRADED CHERNOZEM.
LATERITIC SOILS (LATERITES, TERRA ROSSA, REDDISH-BROWN LATERITIC, RED PODZOLIC SOILS ETC).
CHERNOZEMS AND REDDISH-CHESTNUT SOILS.
CHESTNUT, BROWN, AND REDDISH-BROWN SOILS.
SIEROZEMS, DESERT AND RED DESERT SOILS
SOILS OF THE MOUNTAINS AND MOUNTAIN VALLEYS (COMPLEX)
A — SOIL MATERIAL LARGELY OF ALLUVIAL ORIGIN.
AFTER GLINKA, MARBUT AND OTHERS

ness, and susceptibility to overflow. Some have tried to make maps of slope or degree of erosion separately and then combine these in some way with soil maps. But this is not very practical. Whether a soil may erode on any particular slope doesn't depend so much on the slope as it does on the character of the soil. For this reason the actual degree of slope at which one separates out a phase is a particular figure for each soil type. In one soil this point might be at 2 percent slope while with another it might be at 50 percent slope.[8]

The most common unit in soil classification is the soil type. Some of these are partially subdivided into phases. Types are grouped into series. The series are grouped into families and the families into great soil groups.[9] When thinking of large regions, the great soil group is the most useful unit. Not only does it tell us the general and dominant soil conditions but also the climate and native vegetation. When thinking of fields or farms the soil type (or phase) is the most useful unit because one can be very specific as to the condition of the land and what it can be used for best.

On the map in Figure 23 are shown the principal groups of zonal soils in the world. For the United States the zonal soils and some of the larger areas of intrazonal and azonal soils are shown. These maps, of course, attempt to show the soils of big places only. Each area as shown on these maps has several local soil types—some in-

[8] Percent slope means the number of feet rise for each 100 feet horizontally. Thus a slope equal to that of a right angle triangle, 100 feet horizontally and 100 feet vertically, would be 100 percent or 45 degrees.

[9] These are shown in outline form in Appendix I.

FIGURE 23. This schematic map of the zonal groups of soils is very much generalized and is intended only to indicate the broad distribution of the main groups in reference to continental outlines.

clude hundreds of them. Thus the large area shown as Gray-Brown Podzolic soil includes many small areas that are poorly drained and are not even Gray-Brown Podzolic soils at all, but are Bog or Half-Bog soils, Planosols, or Wiesenböden. Soils grouped strictly according to their internal characteristics—types into series, these into families, and families into great soil groups—cannot be shown except on maps of very large scale, say one to two inches to the mile. Examples of such maps may be seen by looking at any detailed soil map.[10]

Soil maps on a very small scale, like those of the world or of the United States, show groups of soils that are geographically associated but not necessarily alike. In the area shown as Chernozem, for example, the *normal* soils, or those on the gently sloping, well drained upland, are some kind of Chernozem to be sure, but those on steep slopes, in low, poorly drained places, on freshly deposited alluvial flats, or on deep, dry sand are not. For this reason, one speaks of the *region of Chernozem soils,* or the *region of Podzol soils,* meaning the areas occupied by an association of soils consisting of Podzol soils—several families, series, and types of Podzol soils—intermingled with small areas of the other intrazonal and azonal soils commonly found associated with the Podzol. The problem here is somewhat like that of showing vegetation on maps. One shows here the pine forest, there the oak-hickory forest. This doesn't mean that no other plants are in the region—but that there is a group of plants, dominated by pines or by oaks and hickories, as the case may be, along with many other plants normally associated with them.

[10] Typical detailed soil maps for several parts of the country are listed at the end of Appendix I.

The reader is asked to recall that a soil occupies areas. It is something geographic, as well as something physical, chemical, and biological. Climate, vegetation, rocks, and the shape of the land surface are characteristic of the areas also. Each combination of features that make a landscape have cooperated to produce the soil. It is the synthetic expression of all of them. A soil isn't just something one may use to fill a flower pot, or in which one may dig holes for setting out trees. To understand the soil we must look across it as well as in it and beneath it.

The relationship of the great groups of soil to one another, and to people who live on them, may be seen more easily after we have looked at several of the important ones.

7.

SOILS OF THE GRASSLANDS

THE soils developed under grasses are the most productive for the ordinary crop plants under the common systems of farming. Indeed, on most cultivated soils grass, or especially the legumes like alfalfa and clover, must be grown part of the time if their productivity is to be kept at a high level. Many of the farmers in United States have been growing far too little of grasses and legumes in proportion to crops like corn, wheat, oats, sugar beets, potatoes, and fruits. Recently they have increased the amount of grass crops, but even more increase is desirable and will take place as farmers learn more about their importance and their proper management.

The most important group of soils developed under natural grasses is the Chernozem—black soil of subhumid regions. In the United States these are found in the eastern Dakotas, Nebraska, and Kansas, and in small areas in eastern Washington, eastern Oregon, western Idaho, and elsewhere (Figure 21). Also there are large areas in the Soviet Union, Argentina, Australia, and Romania.

Despite their great productivity, these soils were little used for farming before the end of the Thirty Years War in Europe, say about 1650. There are a few exceptions. In some of the valleys in Greece, along the north coast of Africa, and in the Balkan countries, especially Romania, Chernozem soils, or very similar ones, were used by peo-

ple of earlier cultures. Indeed, for a time much of the bread grains for Rome during the height of the Empire came from Chernozems at the fringes, cultivated largely by slaves. Yet the great bulk of these fertile black soils have come into use for farming during the past 350 years. Most of those in the United States and Canada have been farmed less than 80 years. Since the greater part of these soils are found in the interior of continents, far from the ocean or navigable streams, they could scarcely be used by settled farmers until railroads were built. Although a large part of the bread grain for the people of the world is now grown on these soils, it must be remembered that their use followed two very important movements: (1)

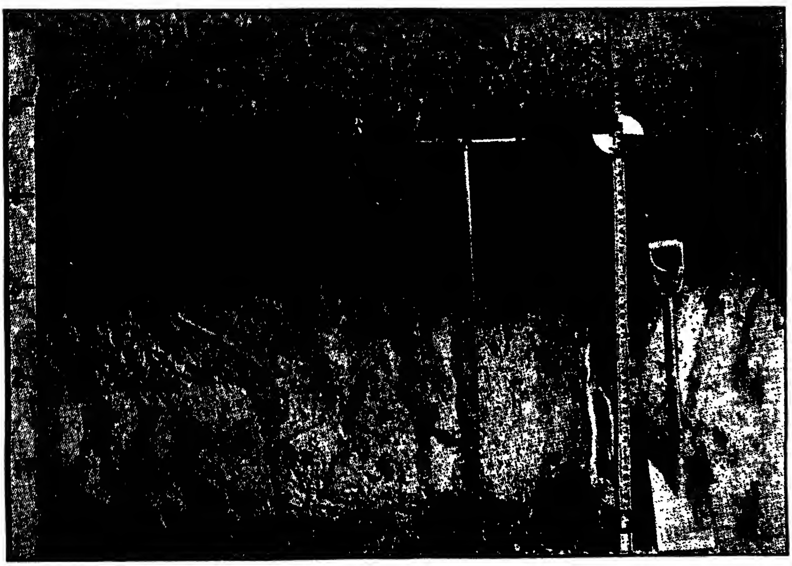


FIGURE 24. Profile of Barnes loam, a Chernozem soil developed from glacial till in eastern North Dakota, eastern South Dakota, and southwestern Minnesota. Note the deep black A_1 horizon. Beneath, is the characteristic lime zone or horizon of accumulated calcium carbonate, which extends to a depth of 4 feet from the surface. (North Dakota.)

the development of science, and (2) the great period of discovery and colonization by western Europeans.

The Chernozem soils are distinctive from the others in very important ways that profoundly influence their use for crops, the kinds of homes and communities they can support, and the way people live and work on them. The landscape is monotonous and sweeping as compared to forested regions. Water is scarce—not so scarce as in the desert but also not so plentiful as in forested regions. Wood for fuel and lumber is limited to small groves and strips along the streams. The climate is usually harsh with cold winters, hot summers, high winds, and sharp showers, in contrast to the more even, more gently changing climate of the forested regions near the sea. Although the new farmer has many uncertainties and hazards, at least the land needs little clearing. Always there is the threat of drought and the eternal hope for friendly rains and a bumper crop.

During the long centuries under the native tall grasses the soils had become enriched with organic matter, so black that people from the forested regions sometimes thought the land must have been swamp! (Figure 24). The rainfall is too scanty to leach the lime out of the soil as in more moist regions. Instead, there is a layer of calcium carbonate, the lime zone, at 2 to 5 feet beneath the surface and in reach of the plant roots. At greater depths there is often a layer of accumulated gypsum ($CaSO_4$) underneath the lime zone. During the years, plant roots have fed on the nutrients from the whole soil to a depth of 2 to 5 feet and left their remains on or near the surface. The soils are not strongly leached and acid like those under the spruce forests. Under natural conditions erosion is slight in these grassland regions; in

fact, erosion is not so essential to keep the soil fertile by removing leached surface material as in more moist timbered areas.

The process of Chernozem formation is called *calcification,* from the word calcium. Since the grasses feed heavily on calcium and return large amounts to the surface, and since there is not enough percolating water to leach it out of the soil, the colloids have absorbed much of it. Such clay is not acid like the clays in the humid forested regions, largely dominated by hydrogen. The clay does not puddle easily, but rather the individual particles cling together in soft clumps, crumbs, or granules. The soil is favorable to bacteria and the accumulation of humus, partially decomposed organic matter which increases the granulation.

The formation of this black soil, rich in plant nutrients and of good structure, is a slow and patient process as individual men reckon time, but still much more rapid than the infinitely slower rock-building and mountain-forming processes. Grasses have a powerful influence. Even in a dozen years they have a visible effect. There have been no accurate figures developed for the rate of soil formation under grasses, but certainly it is more rapid than many people have supposed; perhaps 500 years are required for the formation of a normal Chernozem from loose rock material, like loess or glacial till, perhaps a few less or a few more. Once formed, it may remain essentially the same for many thousands of years if there is no change in the environment.

The colloids do not move much and there is little difference in the clay content of the different horizons, whereas podzolic soils usually have subsoils richer in clay than the surface horizons above or the substrata beneath.

Some people, familiar with podzolic soils, have mistaken the Chernozem soils for young, immature soils, because they lack this horizon of accumulated clay! But normal Chernozem soils never have such a layer regardless of

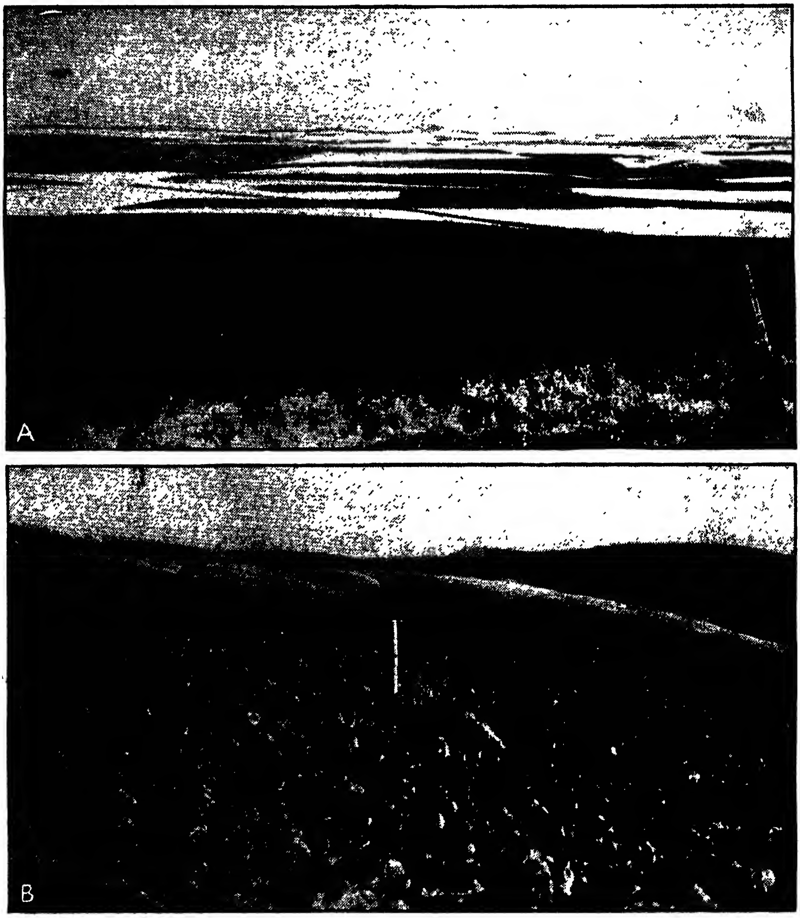


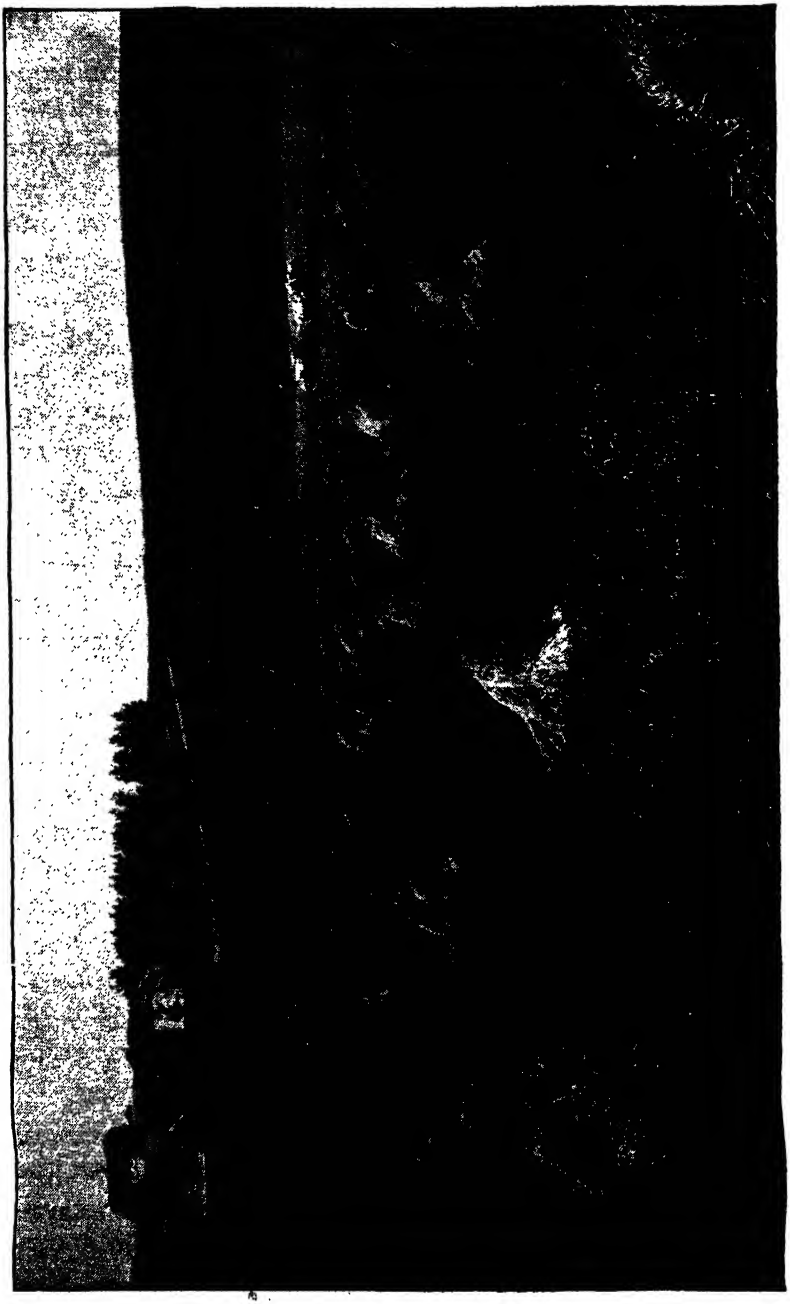
FIGURE 25. Views on Chernozem soils in northeastern Oregon. (A) General view showing the characteristic pattern of fields, alternately fallow and wheat. (B) Close view showing the proper summer tillage, with clods and stubble on the surface to prevent soil blowing in dry periods. White stubble field in the background.

their age. Only in low, poorly drained places or on seepy slopes, where salts of sodium *had* accumulated and then leached away, are there hardpans or claypans beneath the surface.

The normal Chernozem has a granular structure, and the soil is easily penetrated by roots and water. Although this structure can be ruined by excessive plowing and cultivating for many years, the natural structure of the Chernozem is ideal for crop plants. This is quite in contrast to most of the forested soils where even a small amount of tillage is inclined to make the soil dense so it is soggy when wet and hard and cloddy when dry.

Whereas careful management, fertilizers, and lime are required to maintain the fertility of forested soils—many forested soils must even be treated to raise the virgin fertility before good crops will grow—the natural fertility of the Chernozem is very high (Figures 25 and 26). Excellent yields are obtained at once. Of course, excessive plowing and the continual growth of such crops as wheat and corn will ultimately ruin the structure and reduce the fertility, but these soils will endure much. Ultimately farmers must adopt practices that maintain these good qualities, including the growing of grasses from time to time, and the earlier he realizes this the better. Phosphatic fertilizers are already needed on many American Chernozems. But with forested soils the farmer must start at once to do more than maintain—he must create good structure and fertility for good crops.

The farmer on the Chernozem has a narrow range of crops—much narrower than the farmer in humid forested regions. Specialization is essential; but in large sprawling nations like the United States and the Soviet Union such specialization is complementary to specializa-



tion on other soils, including industrial activity. Fruits, vegetables, and many other plants commonly grown on the soils of forested regions are hard to grow, even for the family, on the Chernozem. The farmer grows cereals as the chief crops, usually in large fields. More land per family is needed than in humid regions with more rainfall and where intensive methods are practicable. Thus, the scattered farms are farther from one another, or the villages smaller or farther apart than in humid areas. People are more dependent upon a few crops. They are more concerned about the price of these few crops because they cannot shift to other crops. And they are concerned about the railroads—the freight rates. They must be.

All these facts, plus the constant threat of drought, force people to cooperate. Even those who come from forested regions where folks can be more independent soon learn that they must work together. Many of our greatest movements and ideas looking toward mutual cooperation were born in the regions of Chernozem soils. What is necessary becomes a virtue. Not that the people in other regions don't cooperate! One of the greatest cooperative movements ever started in United States is the great program in the basin of the Tennessee River and, from the point of view of the soil, one of the most significant. All of the soils in this great area are forested (podzolic). Yet people living on the Chernozem have furnished some of the inspiration that got the idea started.

There are other soils developed under grasses besides

FIGURE 26. A characteristic view on Chernozem soils in northeastern Nebraska. These soils are especially adapted to the bread gains grown in relatively large farm units.

the Chernozem. In the United States there is a great area of soils developed under grasses in a humid climate—the Prairie soils of Iowa, Illinois, southern Wisconsin and Minnesota, and northern Missouri. There is no other large area of such soils in the world. They have the dark color of the Chernozem—but no layer of lime. They are slightly acid and have a little concentration of clay in the B horizon. In the same region, on flat relief where the natural erosion was too little, the soils have claypans, dense subsoil horizons, somewhat like those found in forested regions.[1] Yet the normal Prairie soils are nearly as fertile as the Chernozem and this fertility, combined with the greater rainfall, makes them the most productive, when first plowed, of any zonal soils in the world. But if grasses or legumes are not grown for part of the time the structure and fertility will decrease, perhaps faster than on Chernozem. Some lime and fertilizer, especially phosphate fertilizer, is also needed for continuously good crops. Where sloping, these soils may erode too fast and their productivity diminish rapidly. Most of the Prairie soils in the United States are on smooth land and not subject to harmful erosion unless managed very badly, but there are some on rolling land, especially near the streams, that have been seriously injured by being used too much for corn and too little for grasses and legumes.

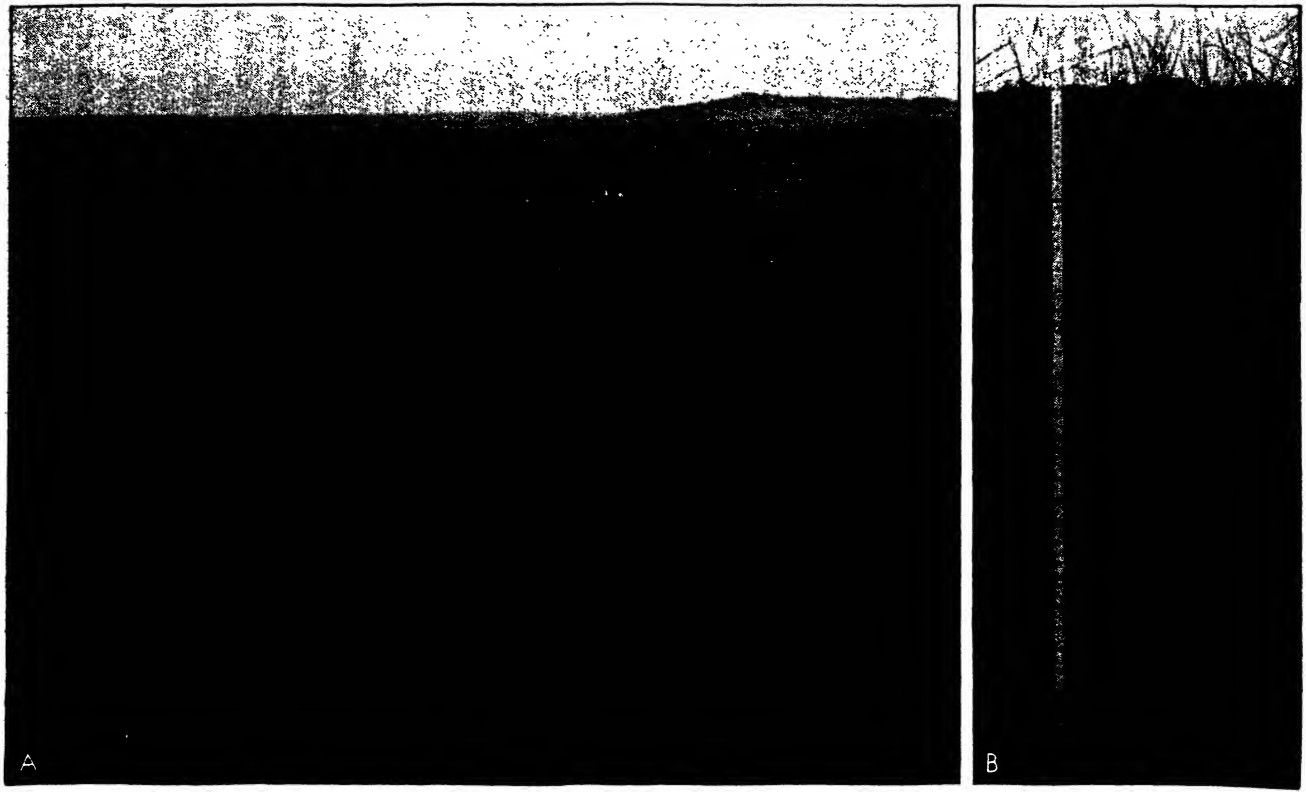
The Prairie soils combine the good qualities of the Chernozem on the more arid side and of the forested or podzolic soils on the more humid side. They have nearly as good structure and as high fertility as the Chernozem and they have nearly as abundant rainfall, freedom from

[1] These soils found on nearly flat land, above the floodplains where they do not receive deposits from streams, with too little erosion to remove the leached surface soil, and with dense layers, either hardpans or claypans, in the lower part are called Planosols, an intrazonal group.

drought, and wide range of crops as the forested soils. Like the soils, the farms and farm communities are transitional. Farms are larger and more widely spaced on the Prairie soils of Iowa and Illinois than on the good forested soils of eastern Pennsylvania, but smaller and nearer together than in central Nebraska or North Dakota on the Chernozem. The people who settled the Prairie soils came from forested regions and cling to their ideas of independence, yet they recognize also the need for and advantages of cooperation like those who live on the Chernozem. It is an area of hard work and little play, of abundance, and of conflicting social ideas—in short a region of vigorous people but uncertain as a group, neither West nor East.

On the other side of the Chernozem, the dry side toward the desert, the soils are brown in color, the lime layer is nearer the surface, the grass shorter, the rainfall scantier and more uncertain, and the farms are still larger. The native grasses are short and do not produce so much organic matter as the tall grasses of the Chernozem and Prairie soils. Leaching is only sufficient to remove the more soluble salts, and the horizon of lime accumulation is within 1 to 2 feet of the surface, where any considerable quantity of lime was contained in the parent material. In most years there is not sufficient rain to cause percolation of water out of the lower horizons into the ground water table beneath. Like the Chernozem, the structure is good for the grains. Between the Chernozem and the Desert soils are two great zonal or continental soil groups, first the Chestnut soils (Figure 27), then the Brown soils. These soils make up the northern and central Great Plains of North America.

Toward the south, the soils are redder, with just a suggestion of the tropics. The Chernozem gives way to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B

Reddish-Chestnut and the Chestnut and Brown to Reddish-Brown soils. This distinction is nothing like so important as that between the Chernozem and Podzol. Yet the wheat and corn of the Chernozem gives way to cotton, corn, and grain sorghum on the Reddish-Chestnut. The monotonous carpet of short grass is interspersed with shrubs at the transition from the central Plains to the southern Plains—from the Chestnut and Brown soils to the Reddish-Brown soils.

People of our culture have only just moved into the Great Plains—onto the Chestnut, Brown, and Reddish-Brown soils. At first the soils were used for grazing and some of them still are. After the American Civil War people came to this region in large numbers. As Professor Webb has said, three new techniques made it possible for the white men to take the land from the Indians and develop ranches—the six gun, barbed wire, and the windmill. They could shoot on horseback, fence huge pastures, and devolop watering places. After the ranchers, the farmers came to the Chestnut soils and then later, especially during the period from 1900 to 1920, they settled on the even drier Brown soils. During periods of favorable seasons and good prices, the magic of a "new" method of farming—"dry-farming"—with alternate grain and fallow (cultivated but not sown) brought settlers and established communities beyond the ability of the soils to support during average periods. A succession of dry years and lower prices made trouble for the people. Matters

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FIGURE 27. Photographs of the Chestnut soil. (A) Landscape. Note the simplicity of this treeless landscape. Neighbors are far apart. In years of frequent drought both cereals and native grasses suffer. (B) Profile. Beneath the friable surface is the characteristic B horizon with a well-developed prismatic structure. The lime zone (C_c horizon) is discernible by its lighter color between 14 and 25 inches.

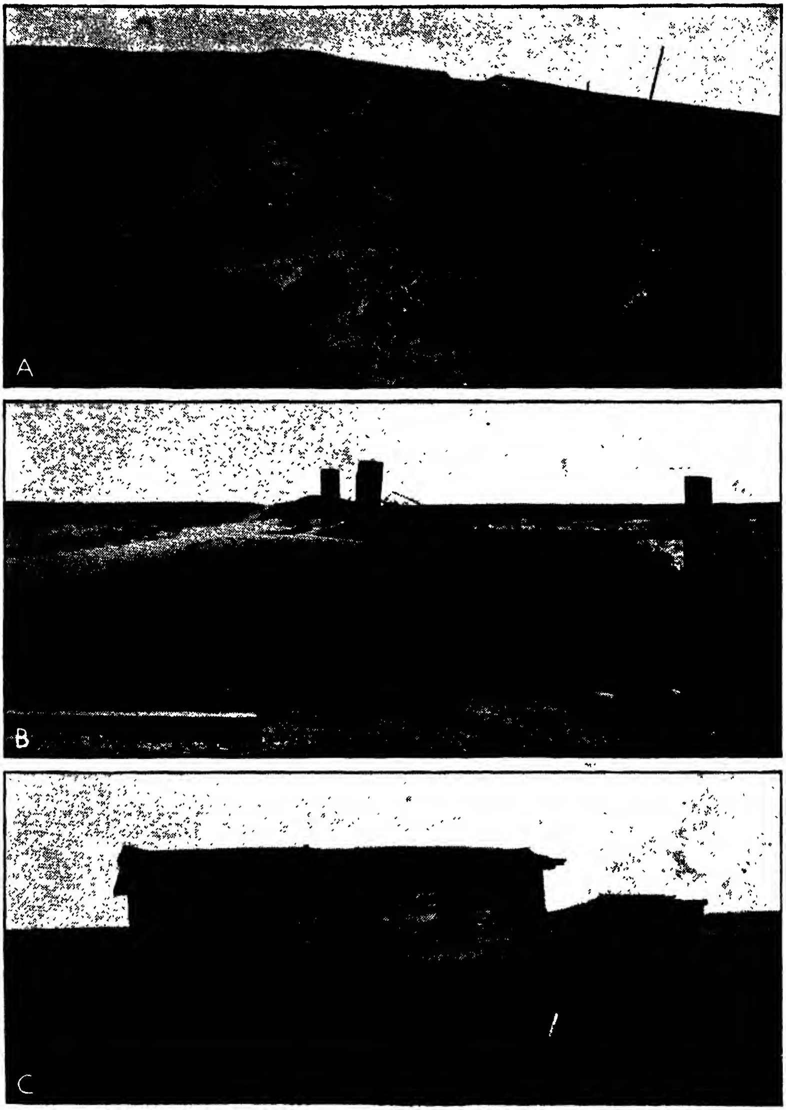


Figure 28. Evidence of poor adjustment of man to the soil. (A and B) Views showing the results of soil blowing during the drought year of 1934 with Chestnut soils that had been plowed too much (South Dakota). (C) An abandoned homestead on Chestnut soils. (Montana.)

became especially bad with the collapse at the end of the "glorious twenties."

Part of the soil was not suitable for cultivation at all and none of it was suitable for cultivation by the methods employed on the forested soils. By plowing the land in the ordinary way and leaving the surface smooth, during periods of drought or near-drought the surface soil began to blow. The dry fine soil swirled upward and collected in great clouds to give rise to immense dust storms, some of which swept eastward nearly to the ocean. A bad series of dust storms swept out of the northern Plains during the terrible drought of 1934 (Figure 28). The following year even more storms came out of the southern Plains. An area about the place where five states—Texas, Oklahoma, Kansas, New Mexico, and Colorado—come together had such bad soil blowing that it has become known as the "Dust Bowl."

Gradually, as the impossible load of debt, mostly accumulated during the twenties, may be lifted, the size of farms increased, the soil unsuitable for crops returned to grass, and proper methods of cultivation developed, this area can come to a stable agriculture. In most instances, widespread soil blowing, soil erosion, or rural poverty indicate that the people are losing their ability to farm the land because of wars, disease, excessive taxation, or some such cause. But here the people have never been in reasonable adjustment to the soil—have not yet learned how the soil should be managed. The soils are fertile and when rainfall is abundant crops are large—yet there are so many dry years that average yields are low. Farmers are now developing a combination of livestock production and grain farming with tillage methods to save all the rain that falls. Cheap electric power for refrigeration

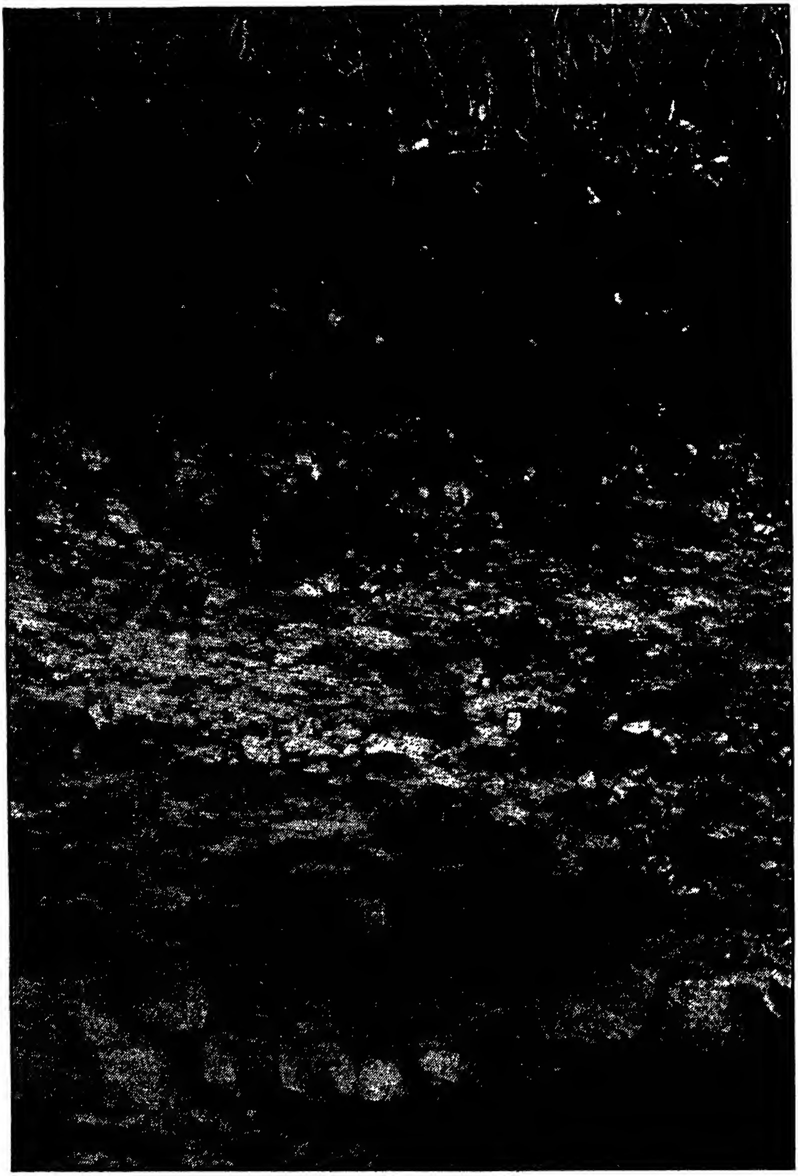


FIGURE 29. A characteristic soil profile developed under grasses on soft limestone. These dark gray, nearly black soils, called Rendzina, may be found on spots of such parent materials, among normal light-colored podzolized soils developed under the forest. (Near Paris, France.)

and for purposes of irrigation will have a big place. Electric power is a new technique as important to the Chestnut and Brown soils now as the six gun and barbed wire were several years ago.

One other group of soils developed under grasses must be mentioned—the Rendzina. Rendzina is a word first used by Polish peasants for dark-colored fertile limy soils. Soils developed from soft limestones or marls nearly always have a grass vegetation even in humid regions. Since the roots of the plants can grow into the soft limy material the plants bring it to the surface and a type of soil formation like that in the Chernozem takes place even where the rainfall may be high. If the deposit is only partly lime, as this leaches out the soil will become acid, light-colored, and forested, in humid regions. Thus the grass covered, dark-colored, non-acid Rendzina soils are found only in humid regions on soft highly calcareous materials. In semiarid regions, they resemble the other soils developed under grasses, like the Chernozem, Prairie, and Chestnut soils, except that the surface, organic-containing horizons are shallower and have little or no brown color. The horizons of a Rendzina soil range in color from black to light-gray, through the grays, while the normal zonal soils range in color from very dark-brown, or nearly black, to gray through the browns (Figure 29). They belong with the intrazonal groups since they may be found in several soil zones.

The famous Black Belt of Alabama has such soils and the "black waxy" soils of east-central and southern Texas are also Rendzinas (Figure 30). That is, had the parent rock not been soft calcareous marl most of the soils would have been forested and light-colored. There are other small areas scattered about. In Europe there are scat-

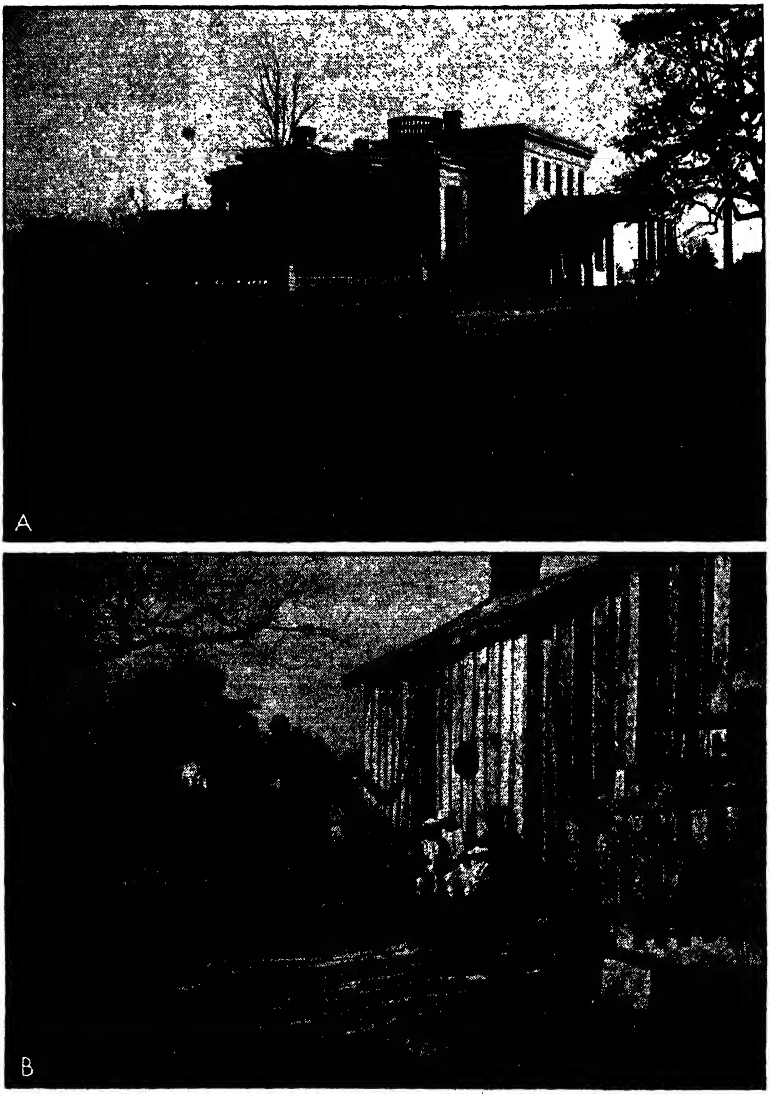


Figure 30. Houses in the Black Belt of Alabama, on Rendzina soil. (A) An old, unoccupied mansion built before the Civil War. (B) An adjacent occupied house (1938).

tered spots in many other soil areas. The open grassy spots that one reads about in the old Greek dramas and stories are areas of Rendzina within the forested soils. Usually they are found on smooth land. On slopes they are likely to be very erosive and if cultivated crops are grown they may suffer serious erosion even on comparatively gentle slopes. In the Black Belt of Alabama natural erosion was great and the natural soils—some of them—were very thin. Now large areas there are almost white because the dark-colored surface soil has been washed away. Most Rendzinas are on nearly flat land. Usually they are black, quite fertile, and high in clay content. During wet seasons they are often sticky and hard to cultivate, and probably there are no more "muddy" soils in the world.

Salty soils, or soils influenced by an excess of soluble salts, are found throughout the region of Chernozem, Chestnut, and Brown soils, and extend into the deserts. Usually they exist in small spots from a few feet to less than one-quarter mile in diameter, on seepy slopes or in small depressions where salty water has accumulated. There are, however, some large areas in the drier regions, developed in old playas or lake basins. As the water evaporates the salts are left. Very generally it may be said that salty soils are found in the arid regions in the same kinds of places where peat and muck soils are found in humid regions.

In arid regions, the moist places are rarely continuously moist, but become dry and salty a part of the year. Ordinary plants will not grow in soil containing much salt, say more than 0.5 percent by weight. This figure depends upon the kinds of salts and the kinds of plants and their stage of growth. Some plants will show injury if the salts

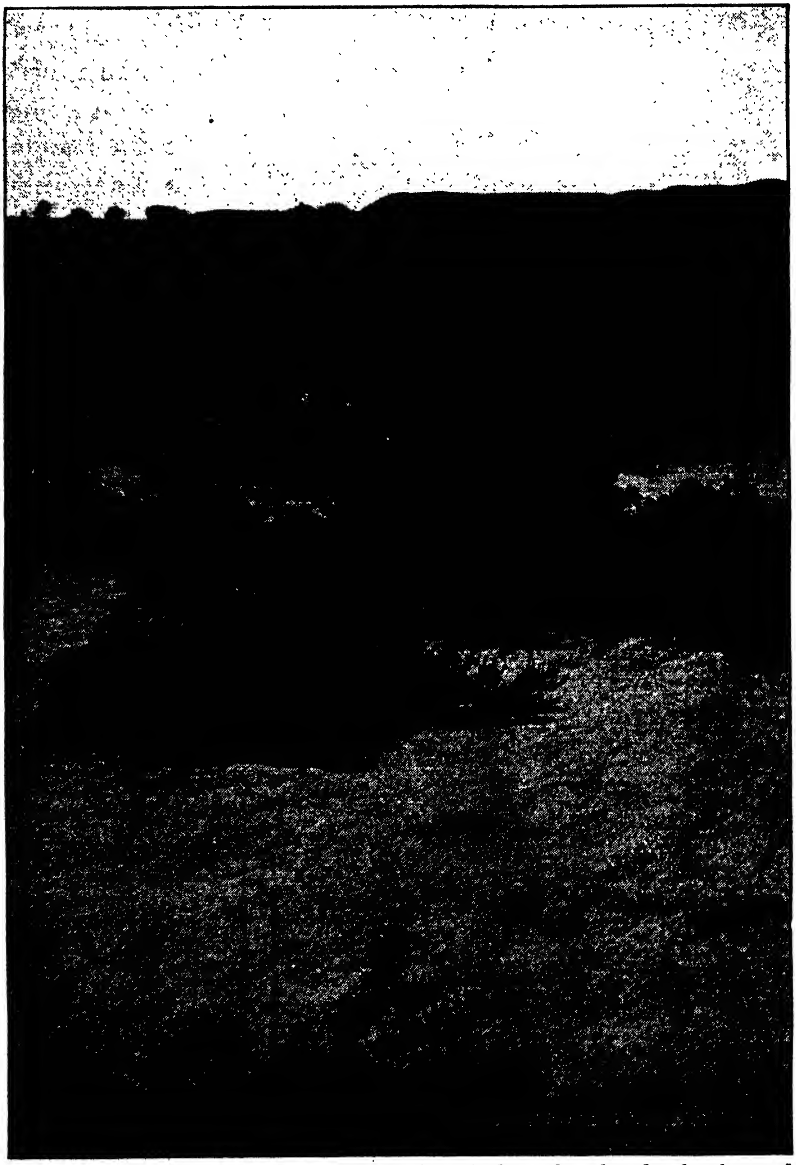


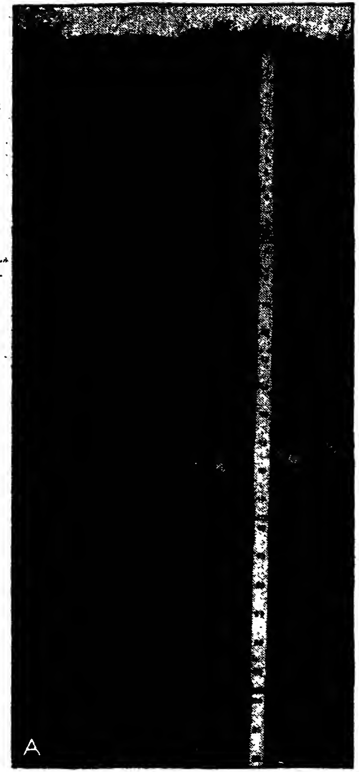
FIGURE 31. Solonchak, or salty soil. Only a few hardy shrubs and grasses can grow in soils having such a high content of soluble salts. Beneath the white, uneven crust the soil is fluffy, soft, and easily spaded. The reclamation of these soils is possible, but is usually too costly to be practicable. Of greater importance is care to prevent their formation from good soils when these are irrigated. (Utah.)

are as plentiful as 0.2 percent, whereas a few salt-loving shrubs can grow in soils having as much as 10.0 percent salts.

These salty soils are best known as either salty or saline soils or, in the international nomenclature, as *Solonchak* soils (Figure 31). In western United States they are also known locally as "white alkali" soils or simply as "alkali" soils. Since they are not always highly alkaline, these latter terms are misleading. Because of the excess salts, the fine clay, or colloid particles, are flocculated, grouped together in small granules or crumbs. Frequently there is a brittle crust on the surface, with a fluffy layer just beneath. Such soils are called "puff" Solonchak, and walking over them is much like walking over fluffy snow some few inches thick that has a brittle crust on the surface.

Sometimes the salty water has flooded over the soil, as in a flat lake basin, but more commonly the salty water has come up through the soil by capillary action, as in a lamp wick, from a shallow water table. Any slight variation in the soil material causes differences in the amount of salts that rise and consequently the soils are almost always very spotty. The soil colloids become saturated with whatever is the principal base of the salt. That is, if the salts are mostly calcium sulphate ($CaSO_4$) or calcium chloride ($CaCl_2$) the colloids adsorb calcium. If they are mostly sodium chloride ($NaCl$) or sodium sulphate (Na_2SO_4) the colloids absorb sodium. Actually, there is usually a mixture of several kinds of salts but if there is any considerable quantity of sodium salts, the adsorbed sodium ions will dominate the properties of the clay.

While the excess salts are present the soils look much alike, but when drainage improves during the ages, and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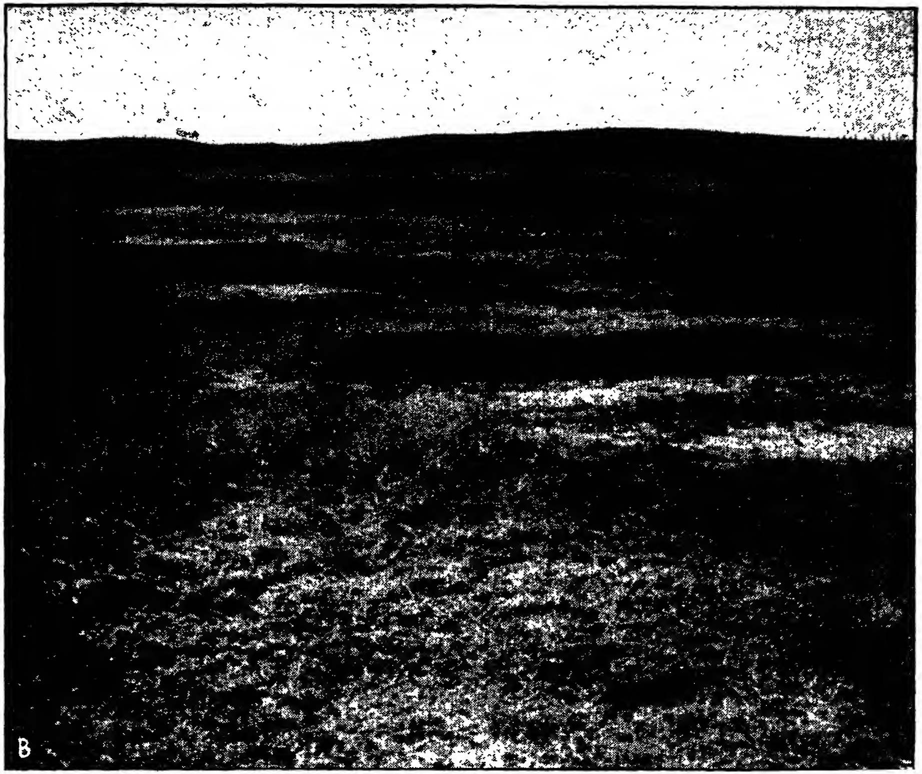

B

the excess salts leach out, there is an enormous difference. The calcium-saturated colloids remain flocculated, granulated. But the sodium-saturated colloids become easily dispersed and puddled, or "run-together." The soil becomes highly alkaline—so much so that part of the organic matter is dissolved and forms a dark coating around the soil grains. Some of the sodium (Na) ions on the colloids are replaced with hydrogen (H) ions and combine with hydroxyl (OH) to form sodium hydroxide (NaOH), a strong alkali. This combines almost at once with the carbon dioxide (CO_2) of the air to form sodium carbonate (Na_2CO_3). This salt is especially injurious to plants.

Soils formed by this process are called *Solonetz,* and the process is *solonization.* Such soils develop from Solonchak containing much sodium salt. Usually they are dark colored, very plastic and sticky when wet, hard when dry, and strongly alkaline. Locally in western United States they are also called "alkali" soils, or "black alkali" soils. Since the colloids are easily dispersed, they leach out of the surface layer and accumulate beneath. Although the Solonchaks are not greatly different throughout the profile, except for the surface crust, the Solonetz has a striking profile (see Figure 11). The B horizon has a characteristic columnar structure: the soil exists in hard, vertical prisms with rounded tops.

FIGURE 32. Photographs of a peculiar soil called solodized-Solonetz, widely found in small spots in the northern part of the Brown and Chestnut soil regions. (A) Profile. The surface horizons down to 15 inches are friable and leached of much of their fine clay or colloid. The B horizon is darker colored, much heavier in texture, and has a hard, well-developed columnar structure in the upper part. Note the smooth, well-rounded caps of these columns and the abruptness of the change from A to B. The mottled lime zone (C_c horizon) is evident in the lower part of the photograph. (B) Landscape. Note the shallow, irregular spots caused by the removal of the A horizon, exposing the hard, alkaline clay, in the small spots. (Western North Dakota.)

If the leaching continues long enough the soil will finally become acid and have a deep, light gray layer over an acid blocky B horizon. Such soils are called *Soloth* and the process of change from Solonetz to Soloth is known as *solodization*. There are very few of these in the United States but there are many soils part way between the Solonetz and Soloth, commonly called Solonetz also, but more accurately known as solodized-Solonetz (Figure 32). In the Chestnut and Brown soil regions of the northern Great Plains there are enormous areas containing many small spots of these soils. Frequently the leached surface layer has blown away during periods of great drought, exposing the hard clay of the B horizon in the bottoms of shallow pits. Locally, those shallow pits are called "slick-spots" or "scabby-spots." A great Russian scientist most aptly referred to them many years ago "as small-pox on the face of the steppe."

After the sodium has been lost, the Soloth generally returns toward the normal soil. Thus we might begin with Chernozem, have it change to a sodium-Solonchak through drenching with salts, then to a Solonetz with improved drainage, to a Soloth (or solodized-Solonetz) through continued leaching, and finally back to a Chernozem with the reconstruction of a normal zonal soil. If the salts were calcium salts rather than sodium no Solonetz would be formed, and the soil would go back directly from Solonchak to Chernozem after the improvement of drainage and the leaching out of excess salts. Of course, one needn't look for this to happen before his eyes! It is still another kind of the slow patient cycles of nature where there is abundant time.[2]

[2] The process can be demonstrated in the laboratory during an hour's time, however, by treating a sample of dark-colored soil with a strong salt (NaCl) solution, and then leaching with pure water.

The Solonchak and Solonetz (saline and alkali) soils require special treatments for uses other than rather poor grazing. Their use, and their development under irrigation, will be touched upon in a later chapter. Perhaps we've already given them too much attention, but they are conspicuous and interesting parts of the landscape of Chernozem and Chernozem-like soils in semiarid and arid regions.

8.

SOILS OF THE DESERT

THE desert is a region of little rain. Most of the time it is dry and all or part of the time hot. Most of the rain comes suddenly, as sharp showers on the nearly barren soil. Life is scanty; and throughout the desert there is a life-and-death struggle for the small amount of water. The plants are widely spaced, sometimes with almost the regularity of an orchard. The distances between them grow smaller as one moves to a little moister soil and greater as one moves to a drier one. This regular spacing is the result of an unmerciful competition for water. Animals fight for control of the water holes, and after them man. Powerful individuals, groups, and even nations fight for the control of the streams and water holes of the desert.

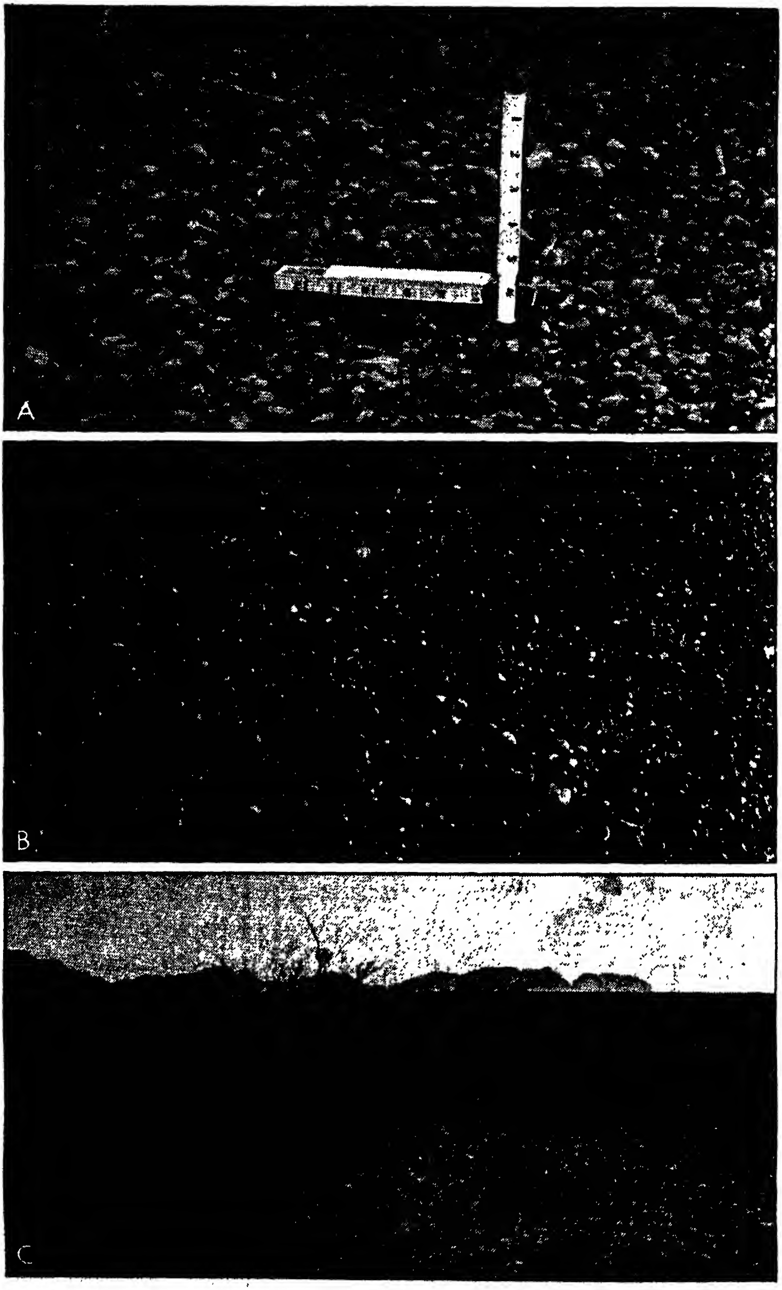
Most of the soil material in the desert has been moved by wind or water. Although there is little rain, erosion is extremely active. The desert is a region of sharp angles. The stream valleys have steep sides, the gentle slopes and valley floors are cut with deep narrow gorges or arroyos through which the water roars for a few minutes after a sudden shower. The weathered rock is washed down slopes as fast as it is formed. Almost no parent material accumulates in place over the rock as in areas well covered with growing plants. Slopes are straight and join other slopes at sharp angles, while in

countries with dense vegetation the hills are rounded and the slopes curved. The contrast may be seen in a hilly region partly covered with growing plants and partly barren and exposed to strong water erosion. There is a place in humid Tennessee (near Ducktown) where all the vegetation was killed by the fumes from a smelting plant. Sharply cut gulleys have formed and there is a bit of near-desert landscape in the midst of rounded and forested hills.

The strong winds and hot, dry climate combine to encourage blowing of the fine particles. After the sand and finer particles begin to blow out of an unprotected mass of material, the blowing goes on until enough pebbles and stones have accumulated on the remaining surface to protect the fine material underneath. Frequently a sort of pavement—desert pavement—covers the surface over large areas (Figure 33). The black sun-baked pebbles and the fine soil underneath together form a little crust under the desert sun and only slow gentle rains can penetrate it. The water runs off the surface during sharp showers as off a slate roof.

The very fine material—silt and clay—blown out of the desert keeps moving until it reaches the sea or a more humid region where it may settle out of the air. During dry periods in the Great Plains when that region was desert great deposits of fine material, loess, were built up in the central part of the Mississippi Valley (Figure 3). The sand accumulates in great dunes, slowly moving hills of sand.

From a previous chapter, it will be remembered that for a considerable time the soil material must be in place, fixed, before a normal soil can develop. Much of the area in deserts is taken up with young soils, but old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Desert soils frequently have well developed horizons. Usually there is a brittle crust on the top underlain by almost fluffy, porous soil. A few inches below the surface there may be a horizon containing considerable clay. This may be due partly to leaching from the surface soil, but more largely to the formation of clay by mineral decomposition in this layer, which is more moist than the soil below or above it. At depths of 2 to 6 feet there are frequently strong hardpans. There are also many salty soils in the desert. In old ponds and lakes the salt may be so plentiful as to prevent all plant growth. When these soils have once been saturated with sodium salts, which later leached out, heavy hard claypans are likely to develop. Such soils are called Solonetz. They extend from the Desert into the Chestnut, Brown, and Chernozem zones.

Thus rippled billowy dunes, desert pavements, steep rocky mountainsides, blackened under the sun, and deep canyons and arroyos occupy large portions of the desert. Along some of the large streams there may be great smooth flood plains and sometimes gently sloping alluvial fans where side streams come into the main valleys. In these places agriculture may develop *if there is water.* Along natural streams, in favored places, and on sandy alluvial fans the Indians of our Southwest have grown and now grow corn, beans, peaches, and other crops without irrigation, or with only the use of local flood waters. The plants are widely spaced, like the native desert shrubs. Over a thousand years ago early Indians built little dams on the small drainways to hold the water back and cause it to sink into the ground. They have also

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FIGURE 33. Views showing well-developed desert pavements. The wind swept the smaller soil grains away until sufficient pebbles accumulated to protect the soil from further movement. (A) Southern California. (B) Southwestern Arizona. (C) Southeastern Nevada.

sought places, more recently along the main streams, where plant roots might reach to the water table. On the upper table lands or mesas in sheltered places, in spots where the water may be concentrated, and along the water courses there is grazing for sheep, goats, horses, and cattle in the desert.

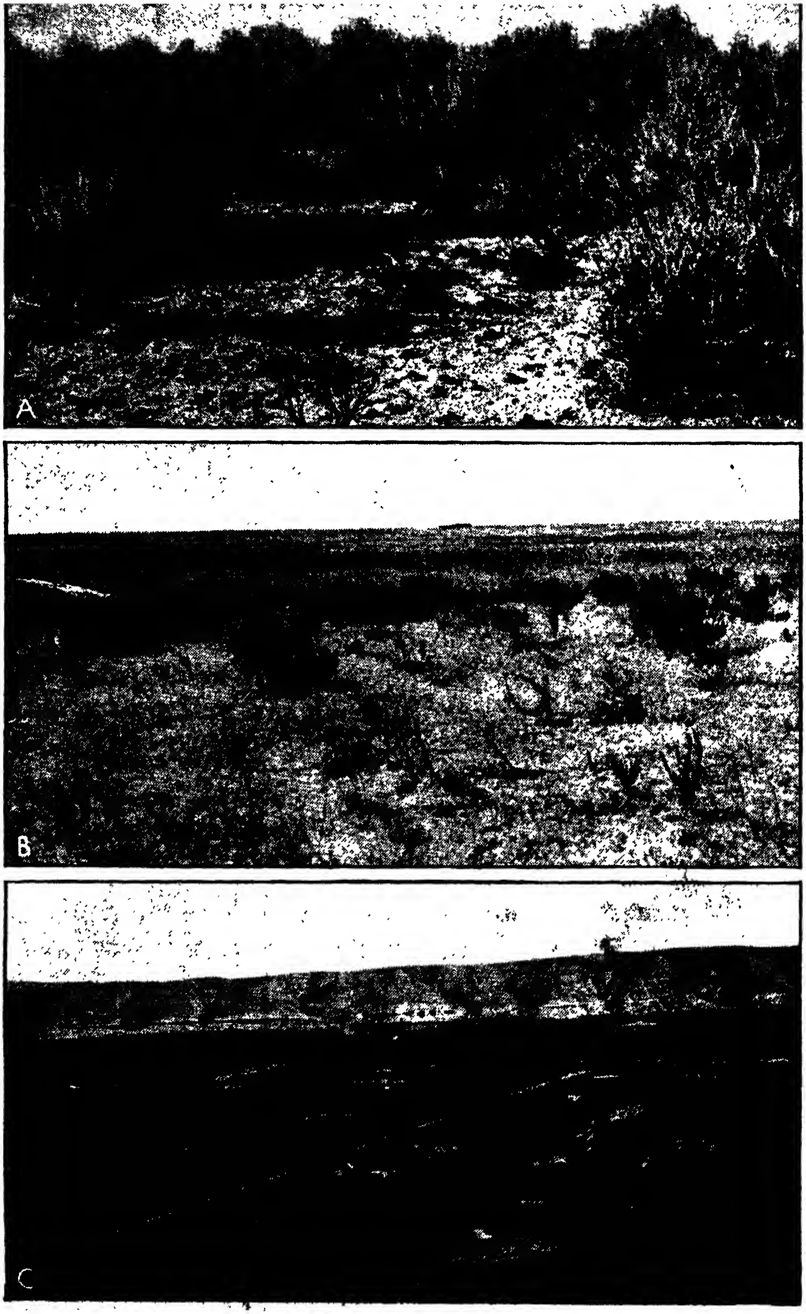
Even at best, the ingenuity of man cannot provide for more than a scanty population, mostly nomadic, in the desert, without great engineering structures. The uncertain climate makes the herdsman move, always looking for new pastures made suddenly green for a short time by the rare rains.

When well-developed agriculture comes to the desert it comes with a bang! (Figure 34). In forested countries agriculture developed slowly—through long-living since before the dawn of history. With hard work and industry a man could clear a piece of land and build a home. In the desert men must work together to build great dams, irrigation canals, drainage ditches, roads, and houses. Everything must be done almost at once. Through engineering men transform the desert into productive land. That is, they do if the soil is good, the source of water dependable, and they make no mistakes. Unfortunately, many mistakes have been made, especially in regard to the soil. The soil must be well drained and have no hardpan layer beneath, otherwise it will become water-logged with irrigation and excess salts may develop, unless proper artificial drainage can be provided. Many soils in the desert are too salty for crops, or may become so with irrigation. The soil must not be too sandy else the water will leach through it too fast. On sloping land care must be taken to prevent seepage water from the high land bringing salts down to the lower land and to prevent irrigation

channels on the slopes from growing into gulleys through erosion.

Many of the soils used for irrigation in the desert region are alluvial soils, too young to be true Desert soils. Of course, Desert soils developed from loess, old alluvial materials, and other deposits are also used. Many physical conditions must be suitable for irrigation to be successful, especially in the true desert where everything depends upon it. Here people must cooperate. There must be rigid discipline. Nothing can be allowed to interfere with the source of water, the dam, or the normal flow in the irrigation canals. Only in the United States has irrigation been attempted on a large scale in a democratic society. In ancient times there were great irrigation works in Mesopotamia, in the valleys of the Tigris and Euphrates rivers. The destruction of their agriculture came when the people were not strong enough to maintain discipline and protect their structural works against the invader. The Arabians carried irrigation to great heights, but again it went to pieces when the government could no longer maintain strict control and protection. In the United States irrigation is in a sense, still on trial. A satisfactory system of social management of a technique requiring rigid control in order to function is not easily developed. One phase of this problem has been expressed dramatically, if not clearly and accurately, in *Grapes of Wrath.*

The place of the necessary field workers in the communities built on irrigated soils has not been defined in a modern democratic state. The intense specialization of individual irrigated areas has allowed high production by growing the crop best suited to the local soil type. But the result has been that the farmers in the whole commu-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nity need extra laborers for a few weeks at the same time. In many places where this problem is serious crops could be diversified in the community, if not on individual farms. Laborers could have more fixed homes and work on different fields in the same community and not need to be always moving. Even with some sacrifice in yield, the whole community might be better off. This phase of planning in irrigated regions is only beginning to be appreciated.

The soils of the southern desert, as in southern Arizona, are reddish in color and are called Red Desert soils while those of the northern region, as in Idaho and the Columbia basin of Washington are called Gray Desert or Sierozem. Next to these are the Brown soils, then the Chestnut soils, and finally the Chernozem in the cool and temperate regions, and in the warm regions the Reddish-Brown and Reddish-Chestnut (see map in Figure 21). These soils and the Alluvial soils associated with them are also irrigated. Many agricultural communities in the Brown and Chestnut soil regions may be made up of irrigated farms, "dry" farms, and ranches as in western Nebraska. All three may even be combined on one farm, although it takes a very skillful farmer to make a success of all these types of farming. On these soils irrigation water may be supplied more as a supplement to the rain than as the principal source of soil moisture. With a good supply of ground water and cheap electric power the farmer can pump enough water to have a simple individual irrigation system on his own farm.

Figure 34. Photographs in the region of northern Gray Desert or Sierozem soils. (A) Close view of the native sage brush. (B) The lonely dry farmer's headquarters scarcely breaks the monotony of the simple landscape. (C) A view of the closely detailed pattern of occupancy on the irrigated soil, which resembles that in the more humid regions. (Washington.)

9.

SOILS OF THE FORESTED LANDS (TEMPERATE)

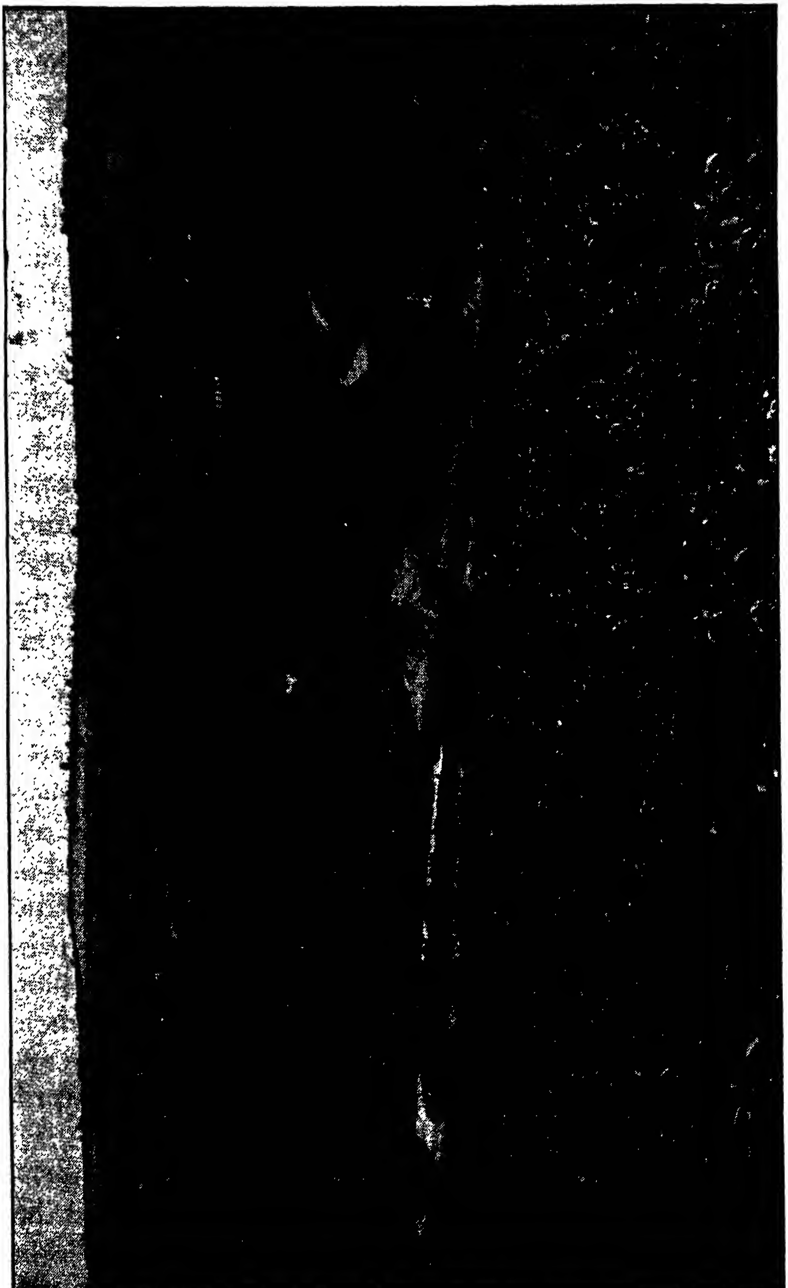
THE people of western Europe and most of those who settled in the United States grew up in a temperate forested region. There are five zonal groups of soils in the forested region of eastern United States, from north to south: (1) Podzols, in the northern Lake States and northern New England; (2) Brown Podzolic soils, in southern New England and eastern New York; (3) Gray-Brown Podzolic soils in the Middle West, extending from the Prairie soils east to the Atlantic Ocean and south to Tennessee; and (4) and (5) the Red and Yellow Podzolic soils of the South, reaching as far west as east-central Texas (Figure 21).

The principal type of soil formation can be seen easily in the Podzol soils. This type of soil formation is called *podzolization,* after the group of soils in which it was first studied; and all the other soils influenced by it are called podzolic even though they are not true Podzols. Although this process has been studied by many scientists, much remains to be learned, especially as to variations in the process leading to different great soil groups. A little later the type of soil formation, or rather weathering, called *laterization* that goes on under hot humid conditions will be discussed. Just now we need only to remember that this process merges with podzolization in the for-

mation of the Red and Yellow Podzolic soils of southern United States, just as the Chernozem process was merged with the tropical soil formation processes to form the Reddish-chestnut soils lying just south of the Chernozem in the southern part of the Great Plains. Even though all of the details of podzolization are not known the main outlines of the process and the conditions under which it goes on are fairly clear.

Podzol and podzolic soils develop in humid regions under a forest vegetation where there is enough leaching of slightly acid water through the soil to make it acid. Although grasses feed very heavily on calcium and other bases and return these to the surface soil in large amounts, most trees feed lightly on them and do not bring enough to the surface to counteract the acidity produced by the carbon dioxide absorbed in the rain water and the organic acids produced by the decomposing leaves and wood left on the surface. Since the trees return but little calcium, the fine clay or colloid particles become saturated with hydrogen, rather than with calcium as in the Chernozem. Such clay particles—those dominated by absorbed hydrogen—do not gather readily in crumbs or clusters, but rather disperse in water, like coffee, and move with the water. The small particles of organic matter also move; in fact, they seem to assist the dispersion and movement of the mineral colloids. For this whole process the soil must first become acid, and this depends greatly upon the amount of bases, especially calcium, returned to the surface by the plants.

Trees vary a great deal in this respect. The evergreens bring the lowest amount of bases to the surface, and the broadleafed trees the most. Even individual trees within any species may vary quite a bit. The leaves of beech



trees growing where the soil material is rich in available calcium will contain more of this base than those of similar trees growing where the soil material is poor in calcium. In a few spots in United States and in many places in Europe, broadleafed trees like maples and beeches, growing where the parent material is rich in calcium, may contain enough bases in their leaves to keep the soil neutral, as in the Chernozem. Such soils have a dark brown color for several inches in depth, a granular structure, and a relatively high content of organic matter. They are called *Brown Forest soils,* an intrazonal group (Figure 35). These soils are more productive than other forested soils. Sometimes they are thought of as "Chernozem soils developed under forest," because the type of soil formation under which they develop is similar to the Chernozem type, despite the more humid climate and forest vegetation instead of grasses. These soils are important in Europe, but are of little significance in the United States. Most of the soils developed under forests, however, are light colored, acid, and leached.

Returning again to the true Podzol: when the soil is acid, a large part of the organic matter decomposes completely to soluble materials that leach out, with only a little humus left behind. In the Chernozem there is a dark colored surface horizon (A_1) some 12 to 36 inches thick, rich in humus; but in the Podzol a layer (A_0) of partly decomposed leaves and twigs lies above the soil. Under the evergreen forest this layer may be as much as 6 to 18 inches thick where there have been no recent for-

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FIGURE 35. Characteristic rural landscape on Brown Forest soils near Belgrade, Yugoslavia. These soils are somewhat like the Gray-Brown Podzolic soils of United States, but are less podzolized and, since the climate is characterized by more gentle rainfall, and because of careful husbandry, there is little increase in erosion with cultivation.

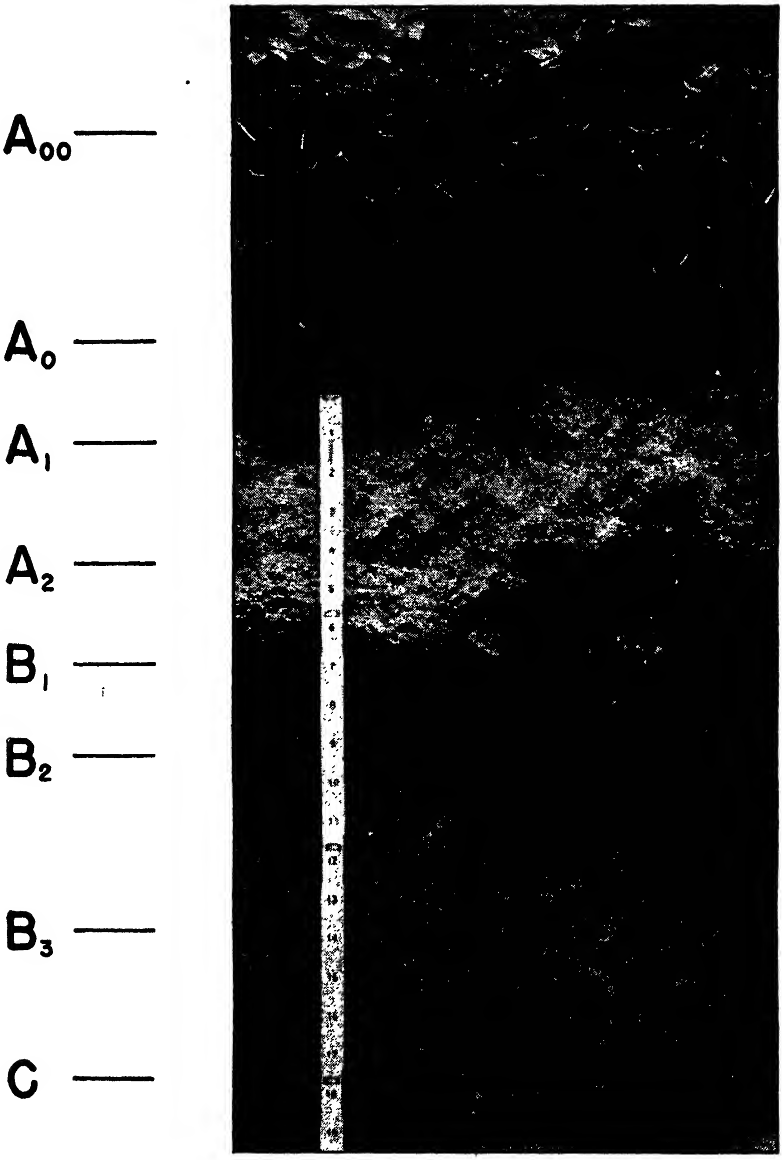

FIGURE 36. Profile of Podzol developed from glacial till of mixed origin under a coniferous forest in eastern Maine. Although the solum is only about 14 inches in depth (plus 8 inches of organic mat on the surface) the soil is mature.

est fires. Just beneath this mat of raw organic matter is the dark colored surface horizon (A_1) containing the humus and mineral soil mixed together. Whereas this is very thick in the Chernozem, it is only 1/4 of an inch to 2 inches thick in the Podzol. Beneath this thin A_1 horizon is the light gray or nearly white, leached A_2 horizon so characteristic of the Podzol[1] (Figures 11 and 36). Organic matter, soluble mineral matter, and even the fine clay particles have been leached out. This gray layer is extremely variable. In young Podzols, or those near the southern margin of the Podzol soil zone, this gray layer may be only 1 to 3 inches thick; but in well-developed Podzols it is 6 to 18 inches in depth. The bottom margin is irregular, with long tongues extending down as much as 12 to 30 inches.

Directly beneath the gray layer is a dark brown B horizon in which some of the organic matter and part of the fine clay leached from the horizon above has been redeposited. If the parent material is sandy, the particles in the B horizon of a well-developed Podzol are cemented into small lumps or even into large hard masses, called *ortstein*—stone formed in place. If the parent material is mostly clay, the B horizon is not cemented into a solid mass of ortstein; instead the soil particles are grouped into firm, angular, blocky lumps, in size between small filberts and walnuts. The A horizons and B horizons, or the solum, are acid. All the water soluble material is leached out and there is no layer of accumulated lime as in Chernozem or Desert soils. The solum of the Podzol is not very thick; usually the parent material is found at 18 to 36 inches beneath the surface of the A_1 horizon, although

[1] Sometimes this strikingly leached, gray horizon is called, incorrectly, the "Podzol" horizon. It is the entire soil that is a Podzol, not any particular horizon.

pointed tongues of the solum may extend downward several inches beneath the general average depth. In the Podzol zone the winters are long and cold and as one goes from this zone toward the tropics the normal solum becomes deeper.

The Podzol soil stands thus in striking contrast to the Chernozem. The profile shows sharp changes in color and in clay content. Although productive for the slow-growing pines and spruces under which it has developed it is not, naturally, so productive for farm crops as the Chernozem. Lime to correct the acidity and fertilizers, especially phosphorus, usually must be added by the farmer. Yet these soils are responsive to management and, where well managed produce excellent pastures, small grains like oats and barley, vegetables, peas, potatoes, turnips, and similar short season crops. With only a few exceptions, throughout the world these soils are used in small farms with a fairly wide range of crops and emphasis upon dairying and potatoes. In contrast to those on the Chernozem, these farms are relatively self-contained, that is, the farmers raise a large proportion of their own food and cut their own wood for fuel and lumber (Figures 37 and 38). The streams, lakes, and dense forests furnish fish and game. The farm family on the Podzol soils is, perhaps, more closely tied together as a social and economic unit than anywhere else.

The Podzol soils are found in the northern Lake States

FIGURE 37. A new home in the Podzol soil region. The adjoining forest affords opportunity for labor and for obtaining fuel and for game. With a low capital people can establish a home on these responsive soils. Small fruits and vegetables can be grown for family use and potatoes and dairy products for sale as the enterprise grows. Even with a low capital investment and a relatively low cash income people can enjoy a good living and many a fine home in this soil region started with such a modest beginning. (Upper Michigan.)

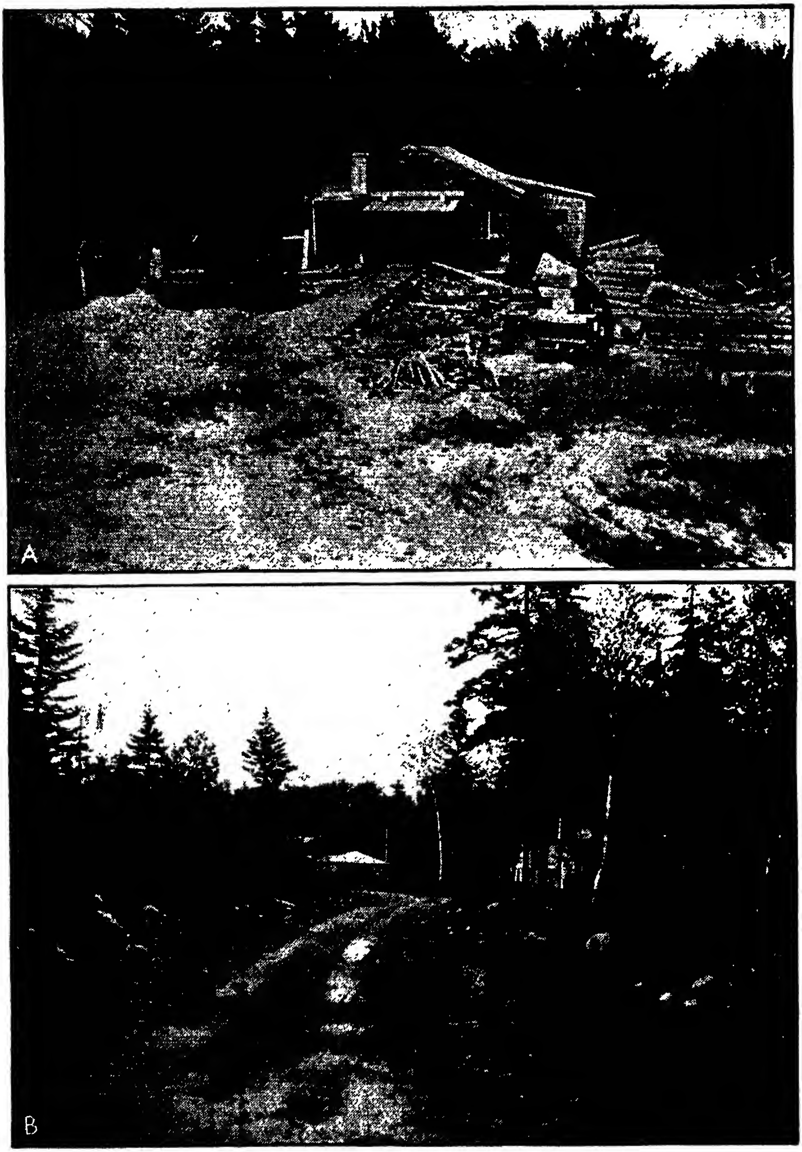

Figure 38. Forestry offers an important source of income in the Podzol region. (A) Characteristic portable saw mill; and (B) a wood camp on stony Podzol soils. (Maine.)

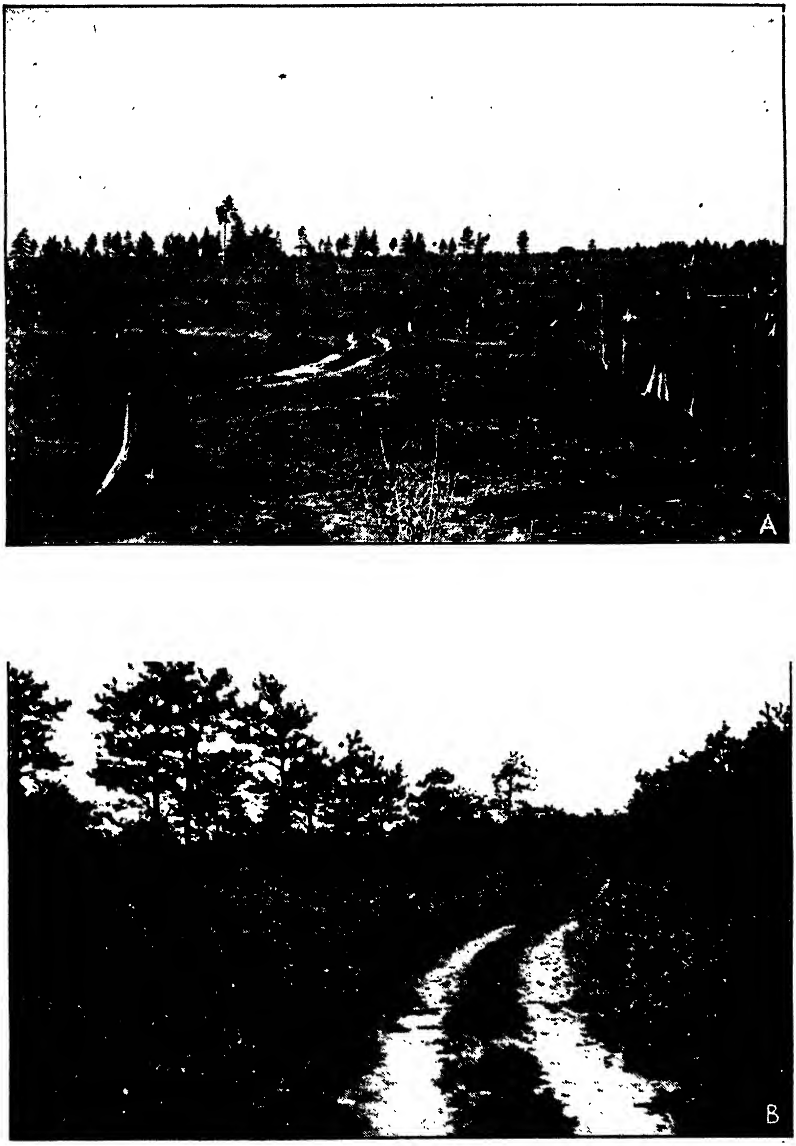

FIGURE 39. (A) Typical view of cut-over land on sandy plains in the northern Lake States. Soil of this character is not productive for crop plants due to its low content of plant nutrients and low water-holding capacity. (B) A characteristic view on dry, sandy soil in the Brown Podzolic region. (Base of Cape Cod, Massachusetts.)


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—the so-called cut-over region—and in Maine and northern Vermont, New Hampshire, and New York (see Figure 39). There are other scattered areas in the mountains. North of the Podzols are the Tundra soils, treeless and with ever-frozen substrata. Most of the humid part of Canada south of the Tundra has Podzol soils except for Gray-Brown Podzolic soils in the very southern part of Ontario. There are immense areas of Podzol in the Soviet Union, some in northern Germany, in large parts of Finland, Scandinavia, and Scotland, and in many mountains throughout the world.

The soils of an intrazonal group, called the Ground-Water Podzol, are somewhat like the sandy Podzols in the appearance of the soil profile. They are found on imperfectly drained, but not swampy, sandy plains throughout the humid forested region (Figure 40). Where the soil is imperfectly drained, the tree roots are shallow, and the trees easily blow over, causing little mounds and hollows, frequently known as cradle knolls (Figure 41). There are important areas of these soils near the Great Lakes and along the Atlantic seaboard, especially in the southeastern states.

Just south of the Podzol soils in New England are the Brown Podzolic soils (Figures 42 and 64). These are very

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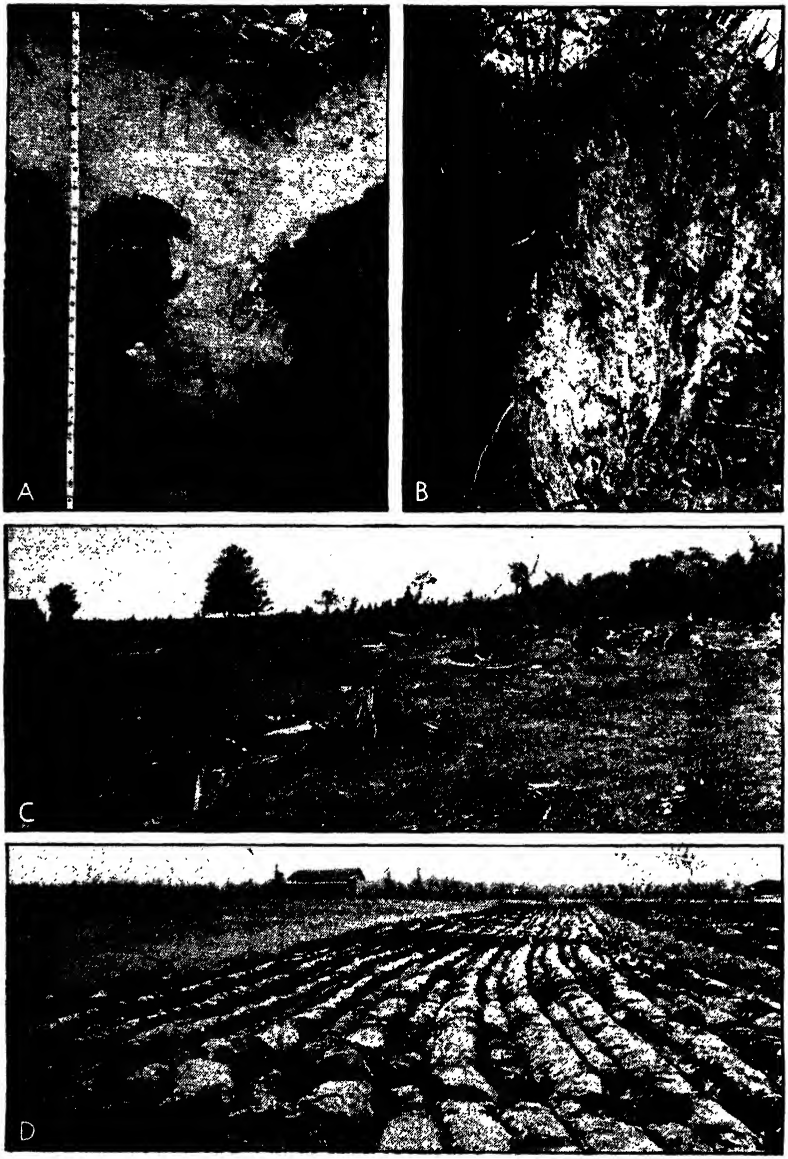
FIGURE 40. Photographs of a typical Ground-Water Podzol soil (Leon series, Florida). (A) Soil profile. There is an exceedingly thin A_1 horizon underlain by an acid, leached A_2 horizon of light gray fine sand, slightly stained with humus in the upper part. The B horizon is sandy but darkly stained and cemented, largely with organic material, into a hard ortstein. The roots of the plants are confined to the A horizon. The water table, in this instance, stood at about 3 feet (near the bottom of the ruler) where the B horizon merges into wet loose sand. (B) Landscape. This soil develops on flat relief from imperfectly drained, non-calcareous sandy material. The land is not productive for ordinary cultivated plants because of its low content of plant nutrients and its unfavorable physical properties for root development.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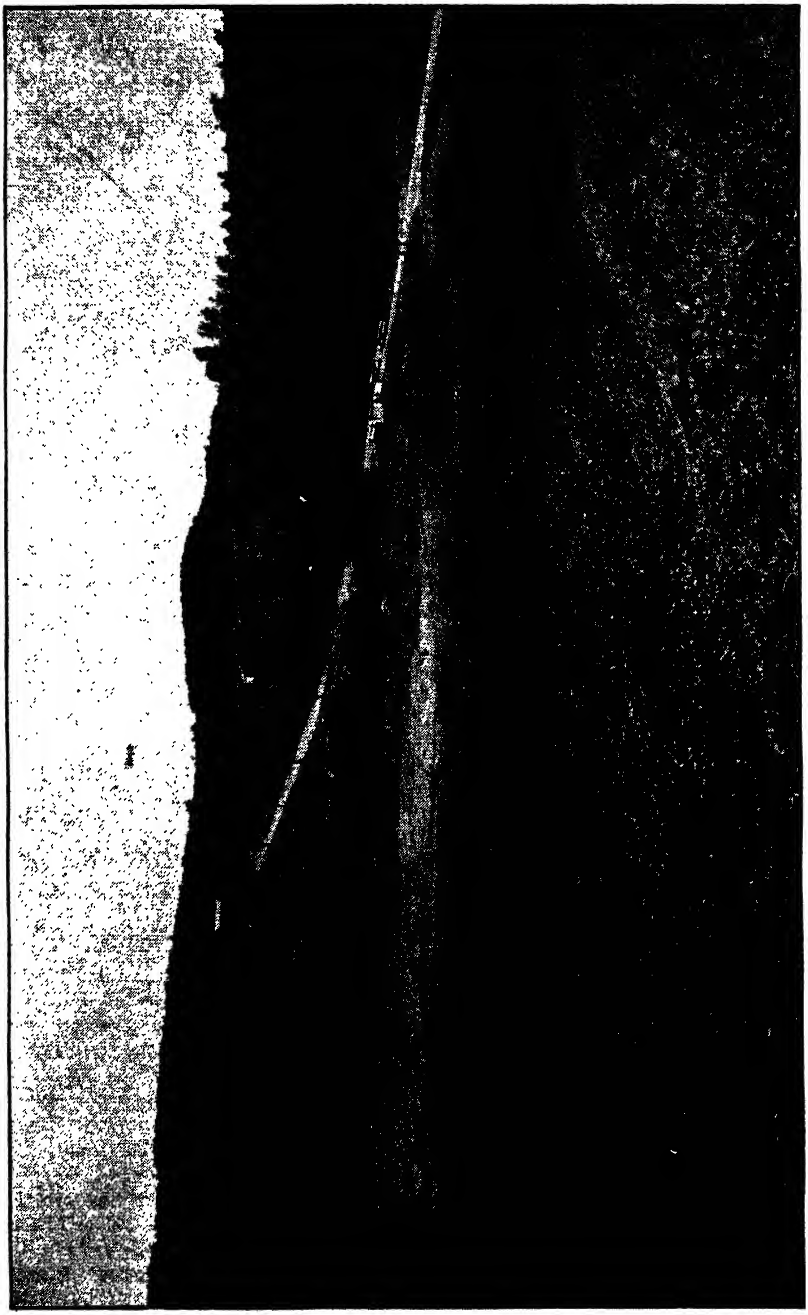
similar to the Podzols except that there is no cemented B horizon nor a gray A_2 horizon, except occasionally a thin gray film. The whole solum is acid but beneath the thin dark A_1 horizon the soil is brown or light brown with only a suggestion of a leached A horizon and a B horizon of clay accumulation. If samples from various depths are examined in the laboratory, however, it can be seen that there has been a movement of clay from the surface layer to the B horizon. The soils have a slightly wider range of crops; especially can more fruits like grapes and apples be grown on these soils.

South of the Podzol and Brown Podzolic soils in our country are the very important Gray-Brown Podzolic soils (Figures 43, 44, 45, and 46). These cover a large area from Chicago to New York and south to central Tennessee (Figure 21). These, or very similar soils, are found in central and western Europe. The modern civilization —called the Western Civilization, as contrasted to Eastern, Arabian, Greek-Roman, or Egyptian—grew and developed on these soils after the beginning of the Christian Era. Since the time of Charlemagne the people of western Europe and central and northern United States have dominated world politics, at least until very recent times. It was not until the middle of the 17th century that the

FIGURE 41. These photographs illustrate micro-relief and its development on northern imperfectly drained Podzols. (A) Profile of Podzol with pronounced micro-relief. Note that the horizons are very irregular and that tongues of the light gray A_2 horizon may penetrate deeply into the solum and actually extend under the B horizon. The irregular dark colored horizon directly under the A is the hard ortstein of the B. (B) Shallow rooted trees easily tip over and, when rotted, leave a little mound adjacent to a little depression. Very few of the roots of this tree reached beyond the gray A_2 horizon. (C) These combinations of shallow pits and low mounds are called "cradle knolls." (D) When plowed, Podzol soils with pronounced micro-relief exhibit a patchwork of very light gray, dark brown, and nearly black spots. (Michigan)



people of this culture began to push out into other areas —on different soils. In our own country, the most important early colonization was on these soils and the Red and Yellow Podzolic soils just south of them. The struggle between the North and South during the Civil War was marked quite closely by the boundary line between the two soil regions (see map in Figure 21). In the years just before the Civil War people had moved west on to the Prairie soils but it was not until after this War that extensive settlement on the Chernozem, Chestnut, and Brown soils began. The people who had lived on the Gray-Brown Podzolic soils for centuries have had many drastic adjustments to make when they went out of this region. As the relative proportion of the total population in the United States living on these particular soils has diminished, changes in our national life have taken place, partly as a result of the different needs and requirements in the other soil regions.

The Gray-Brown Podzolic soils have distinct profiles with well-developed horizons, somewhat less striking than those of the Podzols. The soils are acid and the normal solum is about 30 to 50 inches in depth. The mat of leaves and twigs lying on top of the soil is only one to 3 inches thick, yet the dark-colored A_1 horizon, so thin in the Podzol and so thick in Chernozem, is about 2 to 3 inches thick. The light-colored, leached A_2 horizon is about 6 to 15 inches thick and grayish-brown or yellowish-brown in color. There is a transitional horizon some 5 to 10 inches thick to the well-developed B horizon where fine clay, leached from the horizon above, has accumu-

FIGURE 42. A characteristic landscape in the region of Brown Podzolic soils. These soils are adapted to a fairly wide range of crops with emphasis upon pasture crops. Farms are generally small and usually have a high degree of self-sufficiency. (Vermont.)

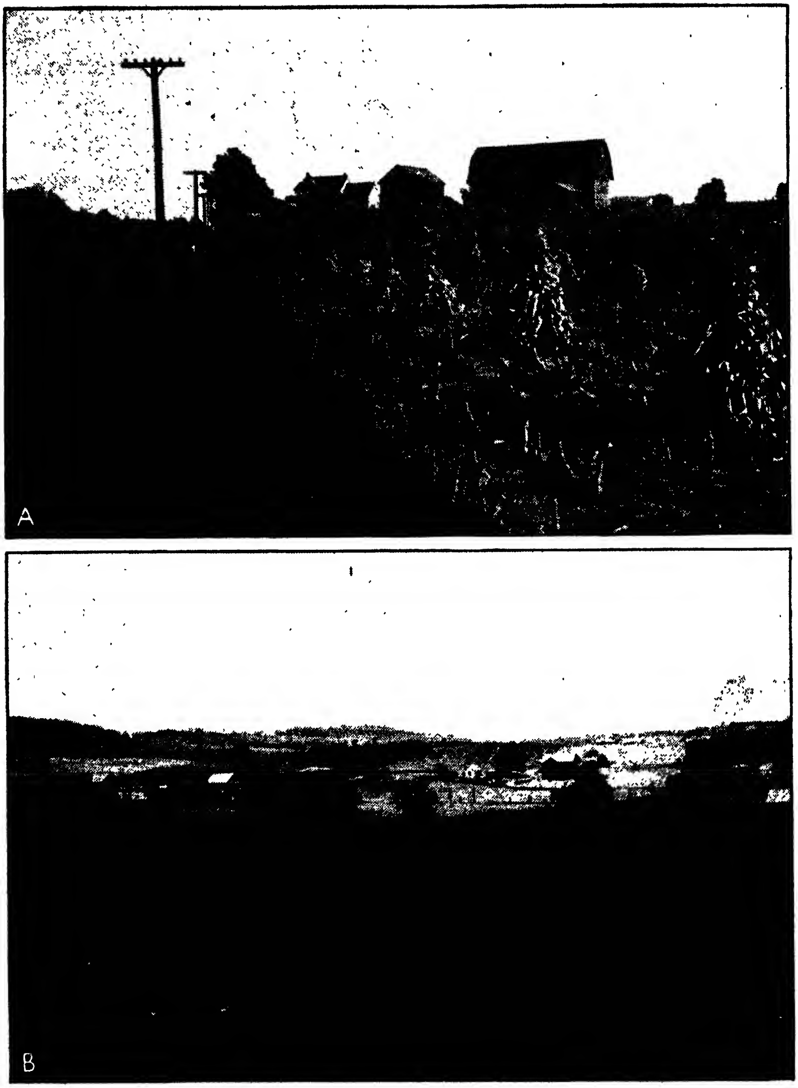
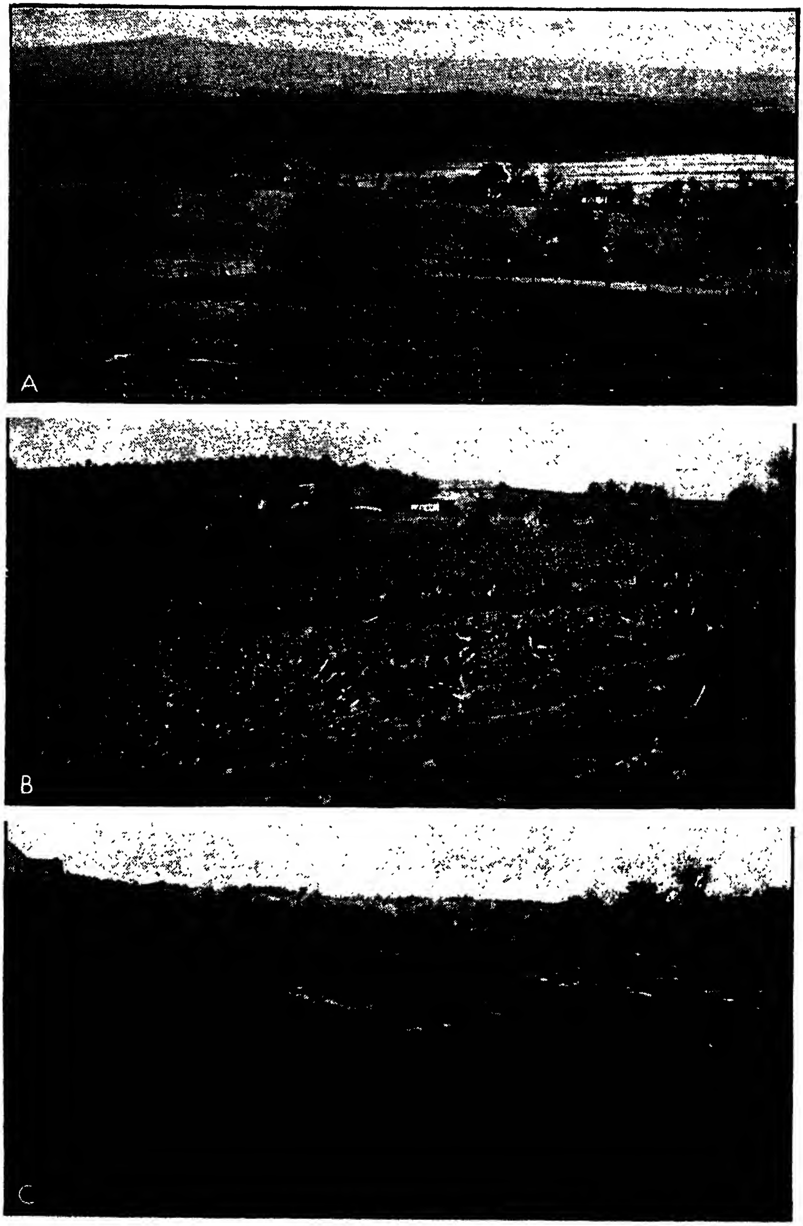


Figure 43. Views on soils in the Gray-Brown Podzolic region. These soils support a wide diversity of crops and lend themselves to general farming with much livestock. Hay and corn occupy much of the land. (A) From glacial till in southern Michigan. (B) From limestone in western Maryland.

lated. The B horizon has a blocky structure and when exposed by erosion, can be made mellow and suitable for a seed bed for crops only with difficulty (Figure 9). These soils are not very erosive, but if they are cultivated too much on slopes the friable surface layer may be washed away, exposing this B horizon. On such soils, the greatest harm from erosion is the change in structure rather than the loss of plant nutrients.

The most distinctive feature of the Gray-Brown Podzolic soils from a social or economic point of view is the wide range of crops that may grow on them. These include the grains, grasses, vegetables—in fact nearly all the important crops except cotton and citrus fruits produced in the United States. Cattle, sheep, and hogs are all produced easily. Many farms in this region have over 15 important sources of income. Besides this, wood and water are plentiful. It is upon such soils that the nearly self-sufficient family farms, characteristic of England, Germany, France, and northern United States, had their greatest development. As industry has grown during the past one-hundred years its greatest development has also been in this same region. With the growth of industry, home manufacturing on the farm, so common in Colonial times, has gradually declined and farmers have made less at home and bought more from the cities. Sometimes this process has gone so far that farmers depend entirely on the crops and livestock sold for cash for their living. When prices collapsed they have been in desperate financial circumstances. With high land values individual farm ownership by the farmer has declined and farming has become less a family way of living and more a business. Frequently this has led to special efforts on the part of the farmer to grow crops for cash—immediate cash—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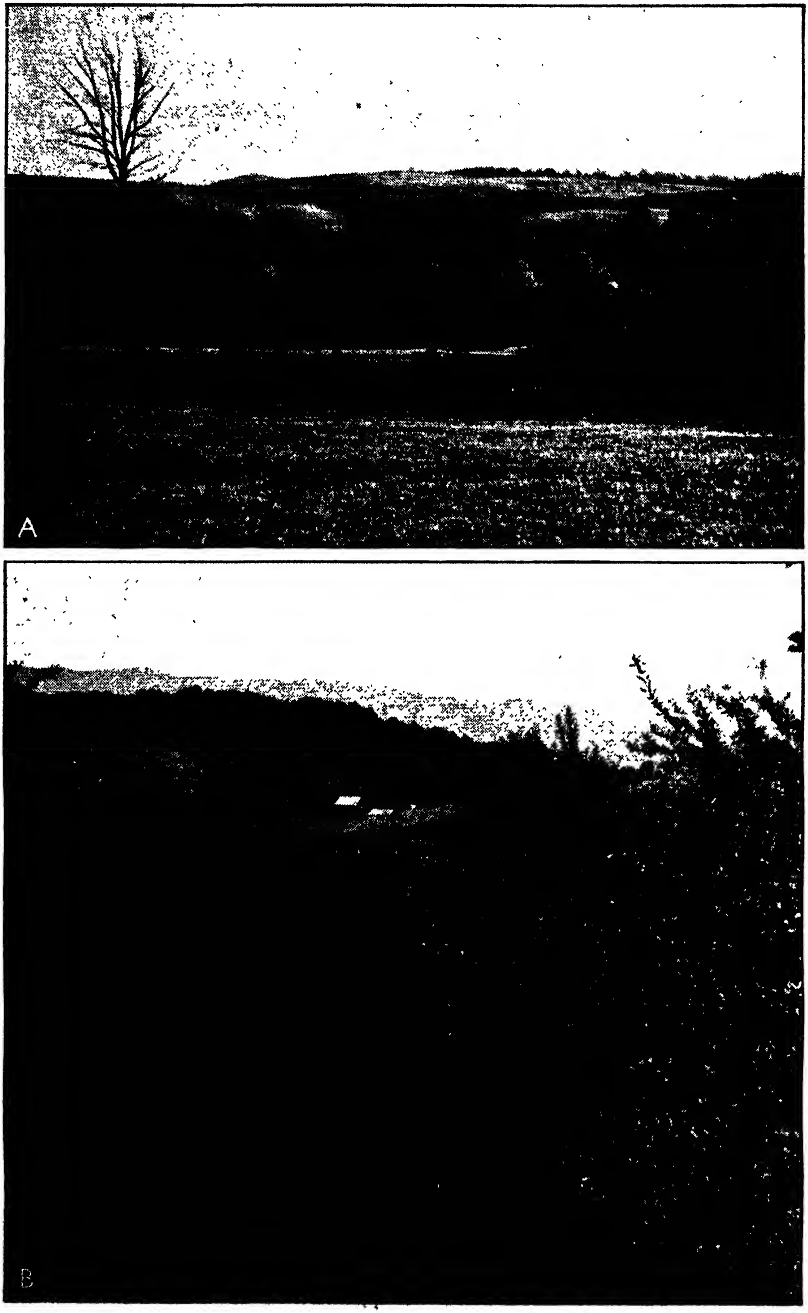
without thought of the future productivity of the soil.

These soils are not so productive for crops, naturally, as the Chernozem; but they are very responsive to management and can be built up to a very high state of productivity for many crops. Most of the farms of several years ago (and many of those of today) in the Gray-Brown Podzolic region were highly diversified and a large percentage of the family living came from the farm. People were independent. Economic cooperation was not so necessary here as in the Chernozem region. This attitude of independence, on the part of both farmers and business men, came to be known by political scientists as *laissez faire*. The attitudes of people on the Prairie soil seem to be somewhere between those on the Chernozem and those on the Gray-Brown Podzolic. The soils are also transitional; they have some characteristics of both.

Associated with the podzolic soils, especially the Gray-Brown Podzolic soils, and the Prairie soils, is a group in which the process of the development of a B horizon has gone to great extremes. These are the Planosols, developed on flat land where there is little or no natural erosion under the native vegetation. In the normal podzolic soils the normal erosion gradually removes portions of the surface horizons; thus the upper part of the B horizon is changing into A horizon, and the B horizon is extending into new, fresh parent material. But in the Planosol the leached material remains in place; the acid, leached character of the A horizon becomes intensified;

FIGURE 44. Views showing the use of the Gray-Brown Podzolic soils in the limestone valleys typical of Maryland, Pennsylvania, and western Virginia, for general farming, including much livestock. (A) General view showing the normal field pattern on these soils. (B) View of typical farmstead with corn in the foreground and pasture on the sloping land in the background. (C) Areas of stony land are common and are best used for pasture.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and the deposition in B is always in the same place, since it too remains fixed. The B horizon of the Planosol then becomes a zone of intense weathering of minerals to form clay, and a horizon of clay accumulation from above, with the formation of a claypan or hardpan.

These soils are less productive for crops than the normal zonal soils associated with them, partly because they are so acid and leached of plant nutrients and partly because of their poor structure that impedes drainage and root growth. In the spring, or during rainy periods, the soils are often too wet and plants cannot root deeply. Then in summer, or during dry periods, the roots are too shallow and plants suffer from drought. Extremes of climatic conditions are much more damaging to crops on these soils than to those on Gray-Brown Podzolic soils. Although there is almost no erosion under natural conditions, when cultivated they may suffer accelerated erosion if badly managed, especially near the base of very long gentle slopes. Such erosion is very detrimental to these soils, already quite unproductive, because it exposes the claypan from which it is almost impossible to make, by tillage, a suitable surface soil for crops (Figure 47). But most of them are too nearly level to be eroded.

Also associated with the podzolic soils, are poorly drained, dark-colored soils. There are three important intrazonal groups of these, the Wiesenböden (meadow soils), Half-Bog, and Bog soils. All these soils are char-

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FIGURE 45. Characteristic landscapes in hilly parts of the region of Gray-Brown Podzolic soils. A large proportion of the soils are too sloping for intertilled crops but can be used for grass, while steep and stony areas are used for wood lots. The lay-out of fields must take account of these differences. On the whole, the soils are adapted to a wide range of farm animals, crops, and fruits. (A) A view in southwestern Pennsylvania. (B) A view in southwestern Virginia near the southern extension of these soils.


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C

acterized by a glei horizon, consisting of grayish or bluish soil, beneath the upper horizons rich in organic matter. Sometimes the whole group is referred to as glei soils. The first is developed under a grass vegetation and has a deep dark-colored surface horizon high in organic matter, but there is no sharp line separating this horizon from the one underneath. When drained, these soils are highly productive for crops—among the richest in the world. Because of the high water table they have been leached but little and have not been subjected to podzolization.

In the region of Prairie soils there are many areas of Wiesenböden in the slightly depressed, poorly drained places. These have been drained with tile and cultivated so that to the observer going across Illinois or Iowa these soils resemble the adjoining Prairie soils so far as one can see from the car or train. But they furnish a striking contrast to the surrounding Gray-Brown Podzolic soils in Wisconsin, Indiana, and Ohio.

The other two groups are developed mostly under forest, and the organic matter lies on the mineral soil. If this organic material is deep, that is, more than 18 inches, the soils are called Bog soils (Figures 48, 49, and 50). In the Bog soils the real soil material is peat that has accumulated under conditions of poor drainage. In some cases, as in Figure 50, the peat has been formed from coarse

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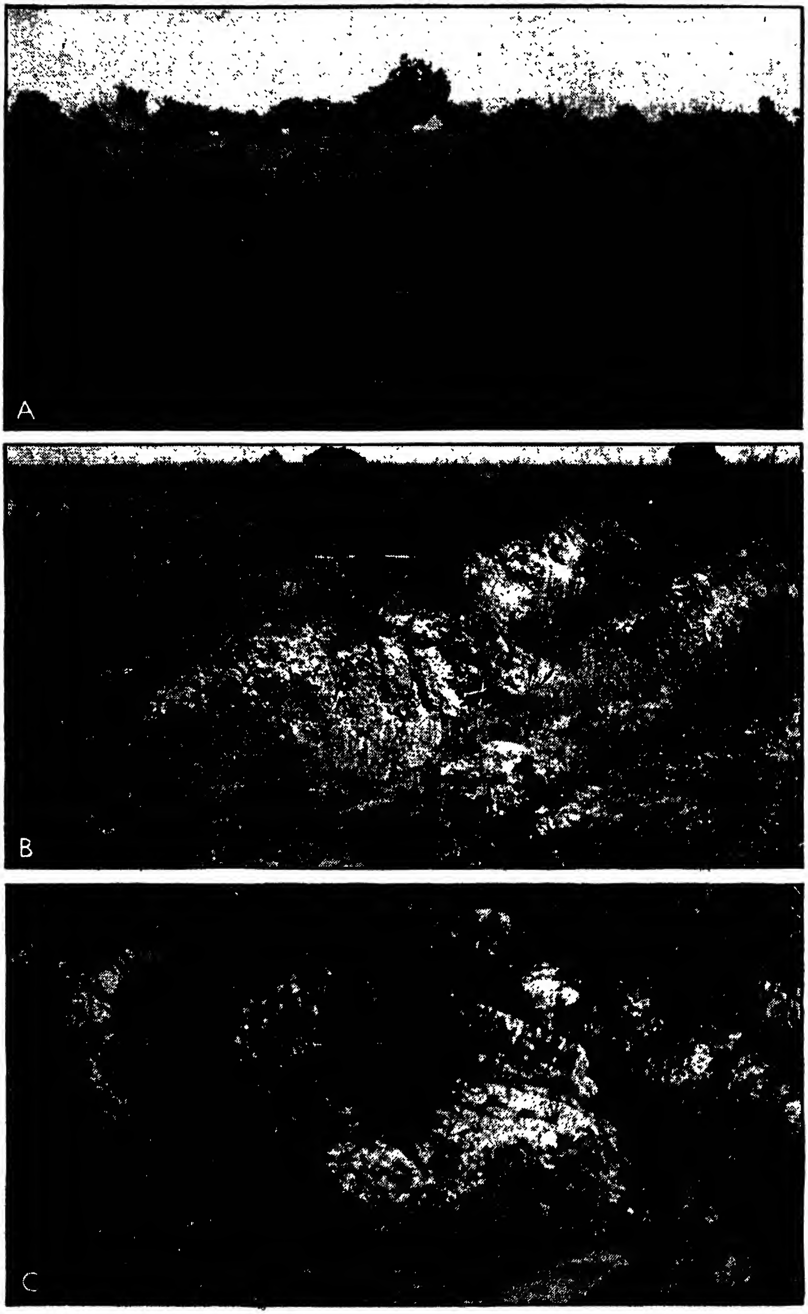
FIGURE 46. Landscapes in the region of Gray-Brown Podzolic soils in western North Carolina. (A and B) These views illustrate a method of strip cropping on the contour to permit using the soil for crops without accelerated erosion. The drainage ways are devoted to pasture. (Courtesy of the Tennessee Valley Authority). (C) Typical farm on hilly land. The productive alluvial soils along the small streams can be used for corn and tobacco, while the hilly land is used for timber and pasture. Small areas of these rich alluvial lands are vital to the establishment of farms in this region.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sedges, grasses, or reeds. Sometimes these deposits may extend to depths of 60 feet. Where they are not too acid, the soils may be drained and used for vegetables and other special crops. Large areas are acid, raw, and otherwise unsuitable for crops, however, especially in the Podzol zone and other regions of podzolic soils.

The Half-Bog soils, as the name implies, consist essentially of shallow deposits of peat over a mineral substratum. Many of these closely resemble the Wiesenböden after drainage and cultivation that mixes the organic and mineral material. A large part of the soils of the famous Saginaw valley in Michigan are Half-Bogs. There are some other large areas, but for the most part these poorly drained soils occur in small spots, interspersed with the normal soils on the uplands (Figure 53). Here and there may be areas of Bog or Half-Bog soils large enough to give a community a distinctive character because of their use for special crops, like celery, onions, or other vegetables.

North of the region of Podzol soils, trees give way to shrubs and the soils have ever-frozen substrata (see Figure 23). In a sense these Tundra soils are related to the Bog soils since they have glei horizons and peaty surface layers produced by mosses, lichens, and shrubs. The severe and

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FIGURE 47. Views in northeastern Missouri on a Planosol, a soil with a claypan. These soils are characterized by smooth relief, an acid, leached surface horizon, and a compact, relatively impervious B horizon. Plants have poor root growth and are especially subject to drought on these soils. Although such soils had too little erosion under natural conditions, sloping areas are subject to accelerated erosion, if improperly managed, and a few inches of removal is very serious. If the A horizons are removed by accelerated erosion, thus exposing the claypan type of B horizon, the soil is essentially unfit for cultivation under present economic conditions, and would need a long period of careful husbandry to become productive.

repeated freezing and thawing of the solum while the substratum remains frozen causes a great deal of mechanical mixing. As the surface freezes, pressure is brought upon the moist soil underneath, which is squeezed up through cracks or weak spots and oozes out on the surface to be frozen. Frequently great blisters develop that may give way with explosive violence. Such blisters are a hazard to highways, railroads, and buildings. If a building is constructed over the soil and prevents the surface from freezing, water may be forced into it because of the weak place in the surface as contrasted to the frozen ground around it.

The boundary between the Tundra and Podzol is very

FIGURE 48. Cranberries on a very acid Bog soil in the region of Brown Podzolic soils. (Massachusetts.)

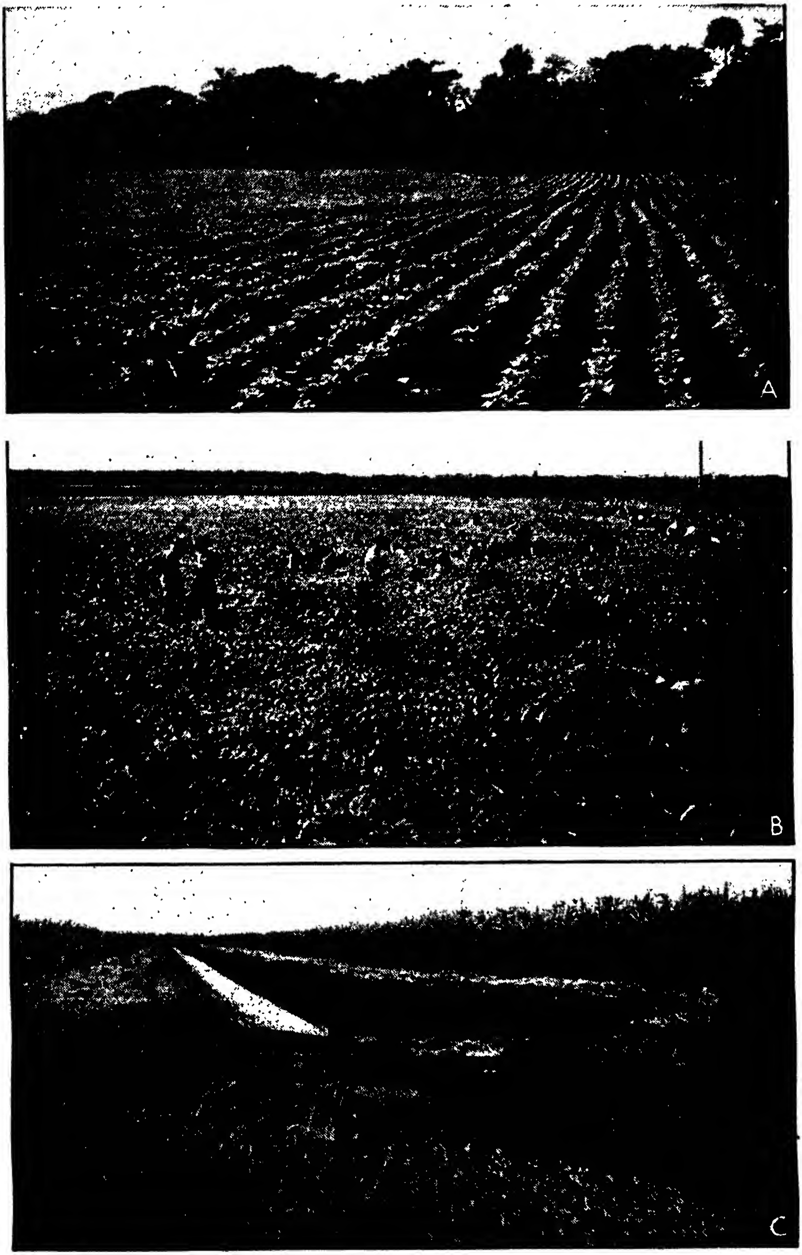
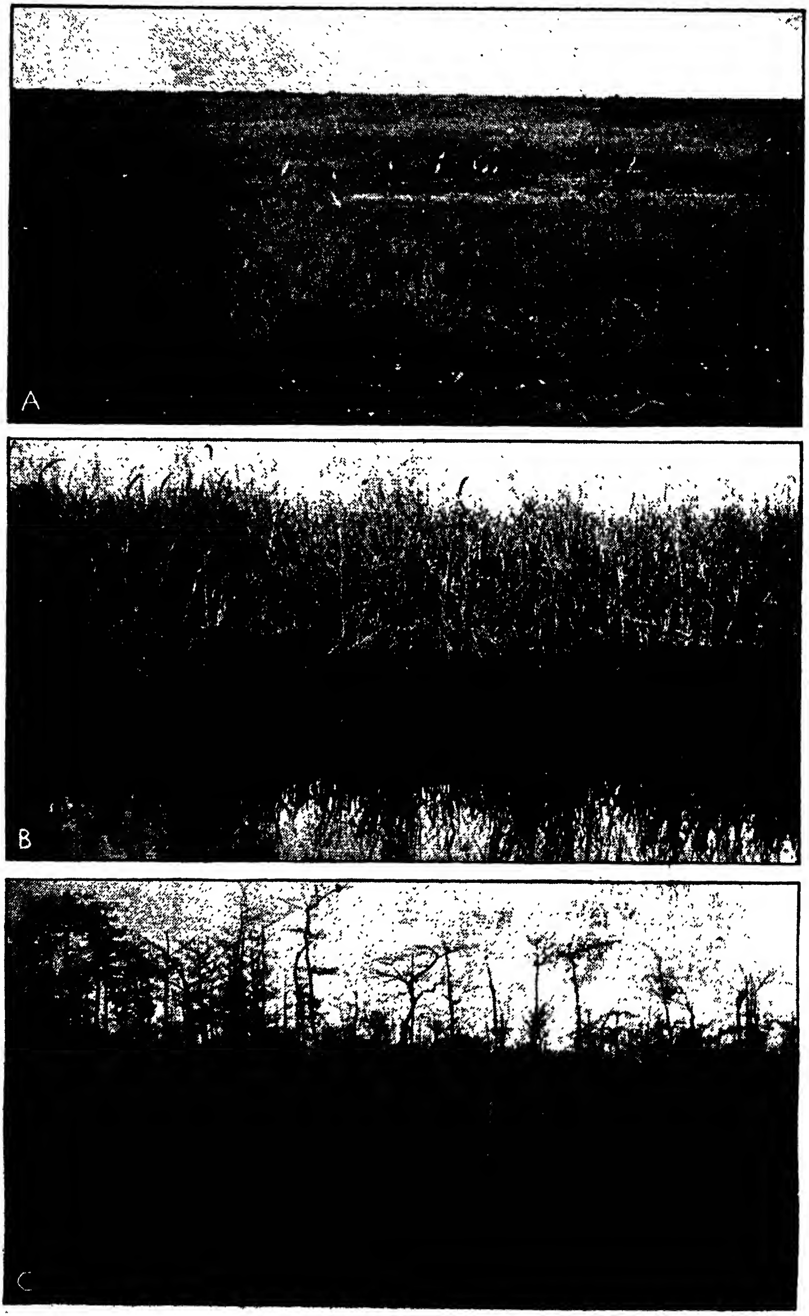


FIGURE 49. Views of crops on a productive Bog soil closely bordering Lake Okeechobee, Florida. (A and B) String beans. (C) Sugarcane.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irregular, and shallow Podzol profiles may be found where the substrata are ever-frozen. Partly because of the early freezing of the mouths of rivers flowing north, there are many wet places and swamps throughout the region of Tundra soils. Much of the land has very shallow soil (Lithosol) or even presents a surface of barren rock.

Going toward the top of a high, ice-capped mountain is somewhat like going from tropical or temperate regions toward the north or south pole in continental areas. Under evergreen forests of cool, moist mountain slopes there are Podzol soils, even on mountains rising out of tropical deserts, and above these—above the timber line—are treeless meadows. The soils are called Alpine Meadow soils (Figure 51). They are dark-brown, have a crumb structure, and produce good summer pastures. Beneath the surface, the soil is streaked with light yellowish-brown and gray. Many of the soils are very shallow, especially on the steep slopes and ridges. Within these treeless areas, and near the timber line, there are many wet and swampy spots. Even below the general timber line there are sometimes black soils, developed under the sedges or grasses, that resemble the Wiesenböden (Figure 52).

The distribution of zonal soil groups on the slopes of mountains is called *vertical* zonality in contrast to *continental* zonality over great land masses. Because of the large proportion of Lithosols on the nearly barren slopes

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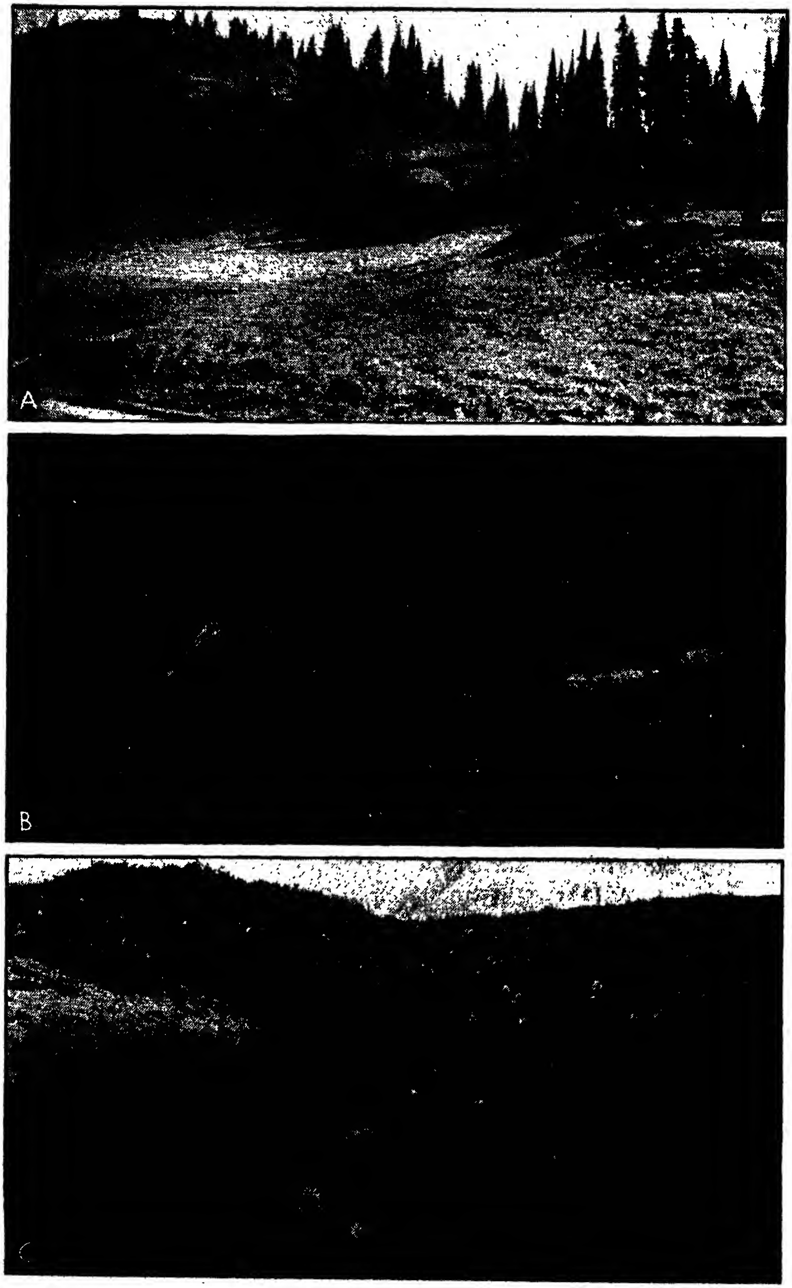
FIGURE 50. View of Bog soil composed essentially of raw peat in the Everglades of southern Florida. Such land stands in marked contrast to the productive lands adjacent to it, although similar in appearance to the casual observer. (A) General view. (B) Close view, showing the characteristic saw grass vegetation. This land is not suitable for cultivated crops according to present knowledge and where drained, as in this instance, presents a serious fire hazard. (C) Small clumps of very old stunted cypress present a dismal aspect on this wet Bog soil, consisting essentially of raw peat.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and the great irregularity in climatic conditions due to irregularities in the mountain masses, the zones are discontinuous and these zonal soils are usually found only in small more or less protected areas. There are several places in the western part of the United States, however, where vertical zonality can be seen easily. In going east

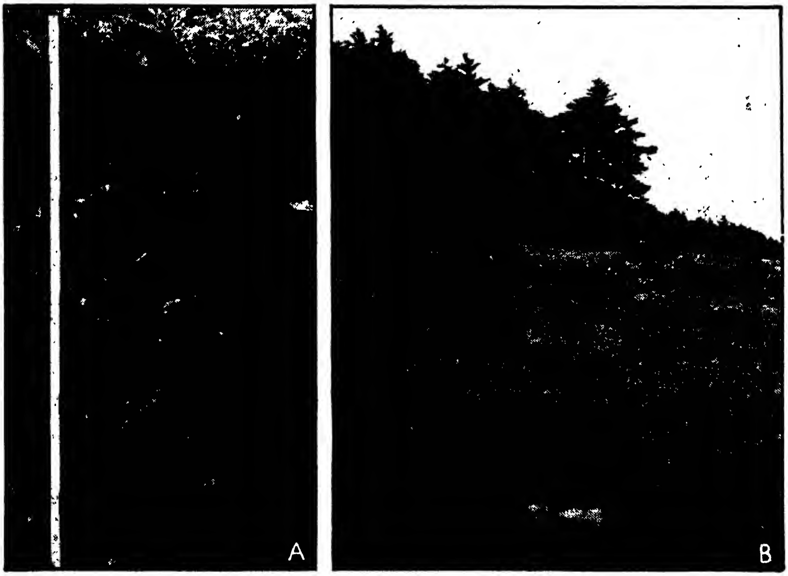


FIGURE 52. A black soil, approaching the Alpine Meadow, developed under sedges on the top of a mountain in the southern Appalachian. (A) Profile. (B) Landscape. (Southwestern Virginia.)

from Pendleton, Oregon, for example, into the Blue Mountains, one passes from Chernozem, over Degraded Chernozem, and to podzolic soils at the higher elevations. In mountainous regions most of the arable soils are young.

FIGURE 51. Views of the Alpine Meadow soils of the high mountains. (A) At the timber line near Mt. Rainier with the grasses and trees fighting for domination. (B) Above the timber line in western Colorado. (C) Close view of the vegetation. These soils are dark brown, friable, and productive of summer pasture.

FIGURE 53. Air view showing the intricate complex association of Gray-Brown Podzolic (brown), Planosol (light gray), and Half-Bog (black) soils in eastern Indiana (see also Figure 18).

10.

SOILS OF THE FORESTED LANDS (WARM AND TROPICAL)

THE Red and Yellow Podzolic soils of southern United States stand in a mid-way position between the soils of the tropics and those of the Podzol region to the north. In hot, humid countries vegetation grows luxuriantly and rapidly. Animals and micro-organisms that decompose it also grow rapidly, so rapidly that when trees are cut down to clear the land for crops they need not be burned as they rot in a few months. Thus the plant nutrients in the soil make a rapid circuit, from the soil to the plant, and back to the soil again. It has been said of the calcium and other bases in normal tropical soils: "The capital is small, but the circulation rapid."

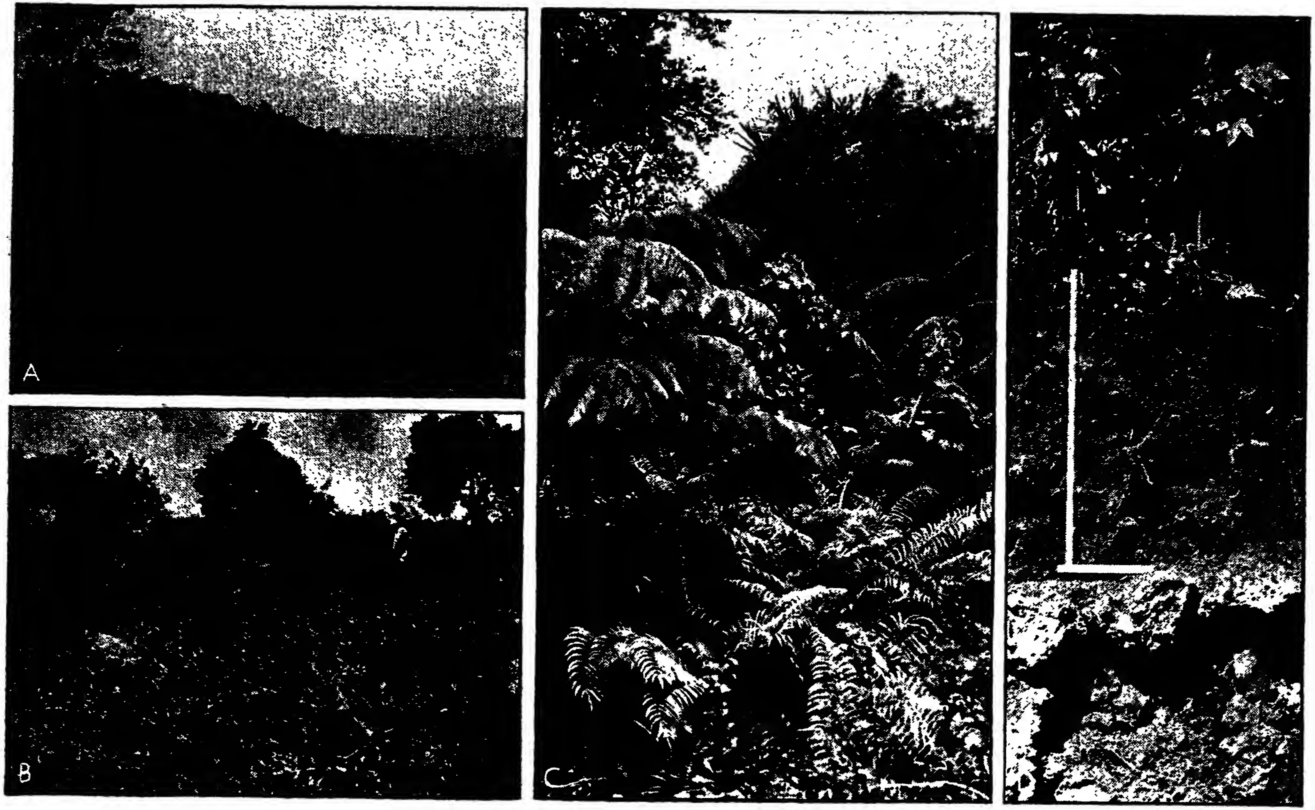
All chemical reactions go forward more rapidly under warm conditions than cold. Not only is the temperature high—it is high throughout the year. Thus, weathering of the rocks goes on faster in the tropics than in cold countries. It seems also that the weathering goes further in the tropics. As the minerals decompose the bases split off, with a loss of silica, as they do in temperate regions, but the process goes further with a more complete loss of silica in the tropics. Well weathered old rocks have lost much except their iron oxide and aluminum oxide. These accumulate. In extreme cases these weathered products contain an equivalent of as much as 30 percent


1 2 3 4 5 6 7 8 9 10 11 12

metallic iron! The high content of iron oxide gives the materials a characteristic red color. A few rocks contain little or no iron and the weathered products are gray, but most weathered material in the tropics is red if well drained. Under conditions of extremely poor drainage the iron compounds may be bluish-gray, and with slightly better drainage yellowish, frequently streaked or mottled with gray or red, or both.

On old weathered rocks under conditions of restricted drainage, deposits of red material, mottled with gray, many feet in thickness have been formed. In place, it is soft enough to be cut with a knife into blocks that harden into stone when allowed to dry. In Indo-China, India, and Thailand (Siam) this material has been used for centuries to make bricks and other building stones for houses, temples, and even statuary (Figure 54). Many years ago a geologist examined the material and called it Laterite from the Latin word for brick. Because of the general similarity between the kind of weathering that gives rise to this particular material used for bricks and the type of weathering that goes on throughout the tropics generally, under conditions of fair or good drainage, the name Laterite has been attached to the zonal soil of the tropics. A soil that consists of material influenced by this process of weathering is called *lateritic* and the process *laterization.*

FIGURE 54. Photographs of old building stones made from the material found beneath the surface of certain lateritic soils in tropical countries. Originally this material was named Laterite, from the Latin word for brick, but now the term has been applied to a broad group of soils in the tropics. This material may be present in thick layers, especially in Ground-Water Laterites. It is soft enough to be cut and shaped with a knife, but upon exposure hardens to a kind of stone. It is characteristically porous. (Photo of specimens furnished by R. L. Pendleton, Thailand.)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Whereas podzolization is strictly a process of soil formation, acting upon parent material produced by weathering, laterization is a process partly of weathering and partly of soil formation. The action of plants, by returning bases like calcium to the surface, are thought to help quicken the process. Growing plants, by reducing leaching and by reducing erosion, aid in the process. For the process to go on, it would seem that the solution around the individual mineral particles must be alkaline, at least part of the year. As laterization goes on, during at least a part of the time the bases and the silica are leached away and iron and aluminum oxides increase. With these chemical changes the fine clay or colloids lose some of their stickiness. The soil material becomes more porous to water and less erosive. Many Laterites with over 90 percent fine clay are as "loamy" and friable as Gray-Brown Podzolic soils in Ohio with less than 30 percent fine clay (Figure 55). They may be plowed in a pouring rain without injury, whereas such treatment would ruin soils in Michigan with a third as much clay causing them to "puddle" and bake into hard masses when dry. It is because of their porous, friable nature that Laterite soils, even on relatively steep slopes, may not erode much when cultivated. Finally in their genesis, a point may be reached when the bases are so reduced that

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FIGURE 55. These photographs from the Island of Hawaii, T. H., illustrate the progress of soil formation in the humid tropics. (A) Recent lava flow with a few plants growing out of deep cracks. (B) Lava flow about 55 years old now covered with vegetation. The soil is limited to a thin film less than one-half inch in thickness. (C) Characteristic jungle of tropical vegetation with one to two inches of soil over the rock. (D) Profile of a young soil, only 24 inches in thickness but able to support a luxuriant vegetation of native or cultivated plants. The soil is permeated with living roots which, together with its open structure and permeability to water, make erosion almost impossible.

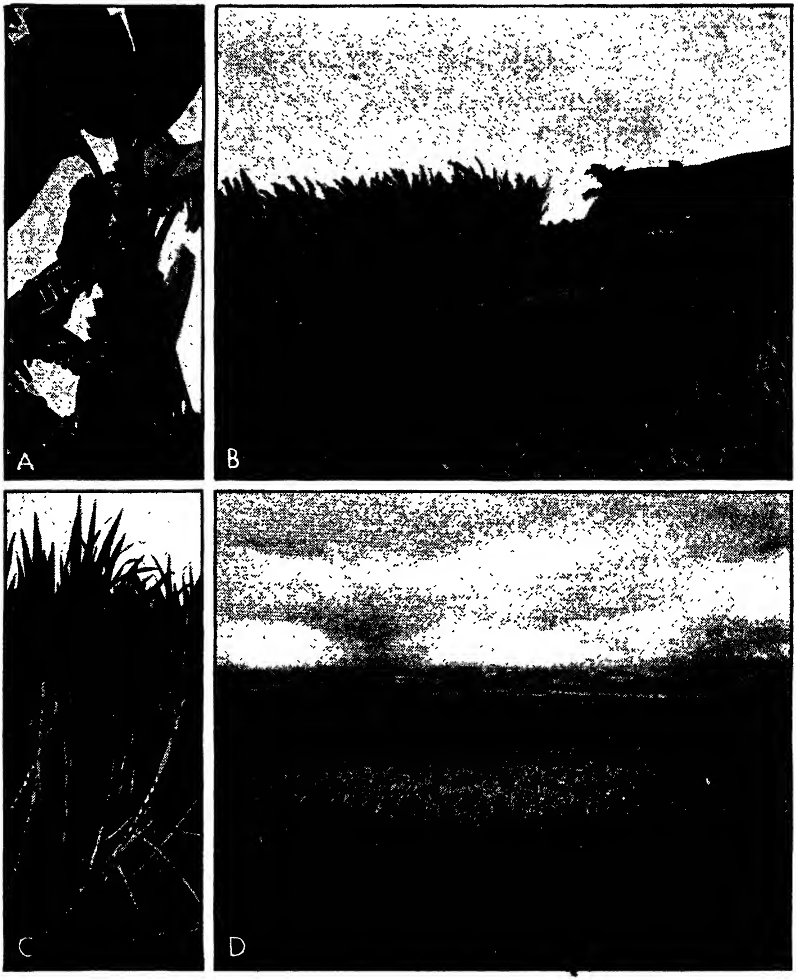


FIGURE 56. Views showing the use of lateritic soils in the humid tropics. They are well adapted to subsistence agriculture of the gardening type, and to highly capitalized plantations. (A) Banana, a typical subsistence or plantation crop. (B) The tropical farmer is a gardener. (C) Sugarcane, a typical plantation crop. (D) View of a portion of the fields on a sugar plantation on the Island of Oahu, T. H.

the soil becomes definitely acid, and podzolization begins upon the material already produced. With rocks high in bases this point may not be reached for a long time—not until a large part of the silica is gone and the soil is rich in iron and alumina. With rocks low in bases laterization may proceed only a short time, to be followed by podzolization.

Since the change in the rocks produced by laterization is great, there is a very wide difference between young soils on very strongly sloping land or in flood plains along streams, and old soils. Where imperfectly drained, heavy concentrations of iron may develop in the soil and lead to the formation of crusts. Such crusts, formed a few feet below the surface at the upper margin of the water table, may be exposed later by erosion as the natural drainage system develops. Of course, in the highlands in the tropics the climate approaches that of temperate regions until well developed Podzol soils are found under the evergreen forests of the high mountains. In dry parts of the tropics Chernozem and Desert soils and the intermediate groups resembling the Reddish-Chestnut and Reddish-Brown soils of the United States, more or less lateritic depending upon the temperature, may be found.

Thus within the tropics is a region of extreme variation in soils, more so than in any other great climatic area. Within the Laterite soil group itself there are wide variations depending upon the age of the soil, the original rock, the slope upon which it has formed, and the changes in slope and drainage that have taken place as a result of volcanic activity, earthquakes, and similar phenomena. The normal soil is likely one in which the parent material has been greatly altered chemically by laterization. Even though the content of clay is high, the soil is open and

porous to roots and water. Almost always the fundamental color is red. The upper part, say the upper three to five feet, shows definite evidence of podzolization with the formation of a leached A_2 horizon and a B horizon in which iron and aluminum from above are being deposited. Yet even within this general profile, the possibilities for variation are enormous.

Most of the well-developed or mature Laterites are low in plant nutrients—some of them very low indeed. Yet many of these have an excellent physical condition for the growth of crops and with heavy fertilization and irrigation during dry seasons will produce enormous yields of sugarcane and other high carbohydrate crops. In Hawaii on Reddish-Brown Lateritic soils a single crop of sugarcane may be as much as 175 tons per acre or 18 tons of sugar (Figure 56). The high temperature and abundant sunlight are favorable to the intense growth of plant tissue. Many of the most productive soils in the tropics are young soils developing from young lava flows, volcanic ash, and especially alluvial deposits. Several of these are kept fertile by frequent additions of fresh minerals or are so young as not to have lost their nutrients by leaching and weathering.

Native people throughout the tropics have developed simple methods for growing their food crops. Perhaps they are more truly gardeners than farmers (Figure 57). Animal fats and dairy products are not easily grown, at least not up to the present, although new types of farm animals, new methods of caring for them, and modern refrigeration may make their production easier. For some reason, not entirely clear, it has been supposed that white people from temperate regions could not live in the tropics. At least, if they did, they could not work them-

selves, and would need to depend upon native peoples, thought to be more hardy, to do the work. Whereas the Europeans who colonized in United States, especially in northern United States, built homes on family farms, in the tropics they developed plantations. They regarded the tropics as a temporary living place. They sent their children back to the homeland for education and looked forward to retirement themselves after their "period of service." People were thought to be subject to diseases and all sorts of difficulties in the tropics. Although they actually are now, this is not so much because it is tropics as because of poverty and poor sanitation among the natives.

Of course, people must make some rather drastic adjustments in going from one soil to another—from Gray-

FIGURE 57. A vegetable farm on Reddish-Brown Lateritic soils. (Hawaii.)

Brown Podzolic to Chernozem or to Laterite. But the idea that white people can only live in the tropics without working has been quite well destroyed. The idea was convenient for those who wanted to make slaves out of the natives; and it still is. The hazard of disease in many of these and other areas may be much less due to the natural conditions, than to the presence of a large population kept in subjection, in poverty, and on the edge of starvation. Disease always thrives among such groups of people, whether it be within the tropics or elsewhere. White settlements have been successful in Hawaii and tropical Australia. The difficulties of settlement on the Laterite soils are many and real, but they won't be met by denying economic opportunity to the bulk of the inhabitants.

The crops best adapted to the Laterite soils are the high carbohydrate crops like sugarcane, rubber, pineapples, and bananas (Figures 56 and 58). At least so far these are the ones that have been grown best commercially under the plantation system of farming. In order to have the normal diet and living of the Western European, manufactured goods and animal fats must be imported. Thus free trade has been essential to these areas, if not with the whole world at least with some country in the region of podzolic soils, as Puerto Rico and Hawaii with United States, Java with Holland, and India with Great Britain. Whether the plantation system would remain without the military forces of the strong nations of the humid temperate regions as a direct or indirect threat is very doubtful. No one today can very safely predict what the normal agricultural communities on Laterite soils would be if they should have an opportunity to develop, free of political or economic pressure from without.

Frequently this substitution of plantations for the native gardens has completely altered the food habits of the people with disastrous results to their health. By substituting such foods as white flour, lard, and pure sugars and starches for their native fruits and roots, their diets have become badly deficient in the essential vitamins and minerals. In many places, greatly increased tooth decay and deformed bones point to serious deficiencies of calcium and phosphorus.

The Red and Yellow Podzolic soils of southern humid United States lie between the Laterites further south and the Gray-Brown Podzolic of the north. They have characteristics of both groups; they are both lateritic and podzolic. They have well developed profiles with

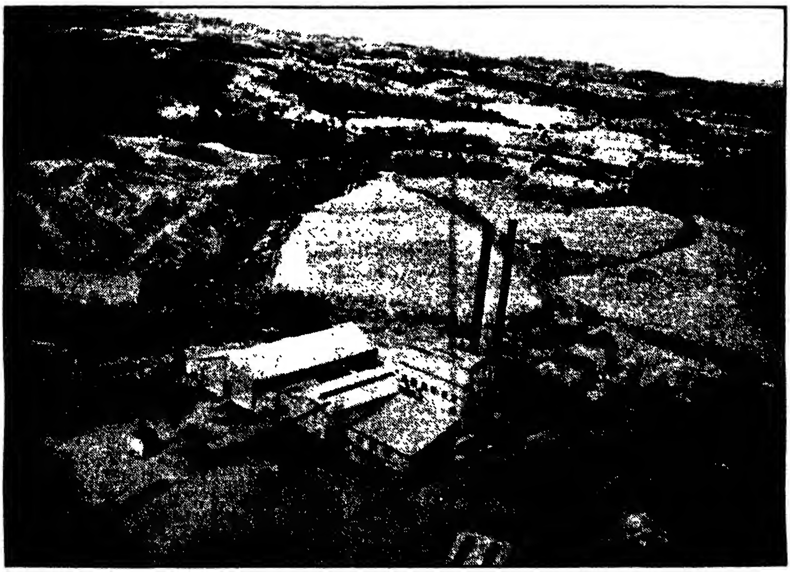


FIGURE 58. A sugar mill on lateritic soils in tropical Puerto Rico. Most sugar mills are operated as a part of the equipment of a sugar plantation. These soils are especially responsive to intensive management in large units.

leached, light-colored A_2 horizons, and darker colored B horizons in which fine clay, leached from above, has accumulated. Their color suggests the accumulation of iron during the weathering process. Between the two groups, the Red Podzolic and the Yellow Podzolic, there is a marked difference in color. The one is distinctly red, with a yellowish-gray, yellowish-red, or brownish-yellow surface soil, while the other is yellow with yellowish-gray in the surface. The yellow group is usually found on smoother, less perfectly drained land than the red group. It is generally supposed that the iron compounds in the one case are not hydrated and are red, while in the other they are hydrated and yellow. In many fields, the red or yellow color of these soils has been intensified through the removal of the surface soil by erosion. The Yellow soils usually are more smooth and consequently less subject to washing, and the Red soils are somewhat more fertile. Neither group has been influenced by laterization enough to be as porous to water as the Laterite. The most erosion in the United States has taken place on the Red Podzolic soils. This is due only in part to the fact that the sloping soils are erosive, because with careful management the erosion can be prevented. It is due also to economic maladjustments affecting the whole region, that make it difficult if not impossible for the farmer to do what should be done, to follow those practices that will keep the soil highly productive.

Although many of the Red and Yellow Podzolic soils have fairly good structure for crop plants, they are naturally acid and low in their content of organic matter and plant nutrients. Yet it must be recalled that the growing season is longer and plants do not require so high a con-

centration of nutrient elements in the soil solution for good growth as in the areas with longer days and shorter growing seasons. Because of the abundant rainfall and comparatively long summer season, organic matter decomposes rapidly and soluble materials leach out quickly. Even under the native forest, the mat of leaf litter is very thin and the dark colored A_1 horizon, so thick in Chernozem, is thin and only weakly developed. On the whole, they are less fertile, and more erosive than the Gray-Brown Podzolic soils lying just to the north of them. On the sandy soils fertilization with nitrogen, potassium, and

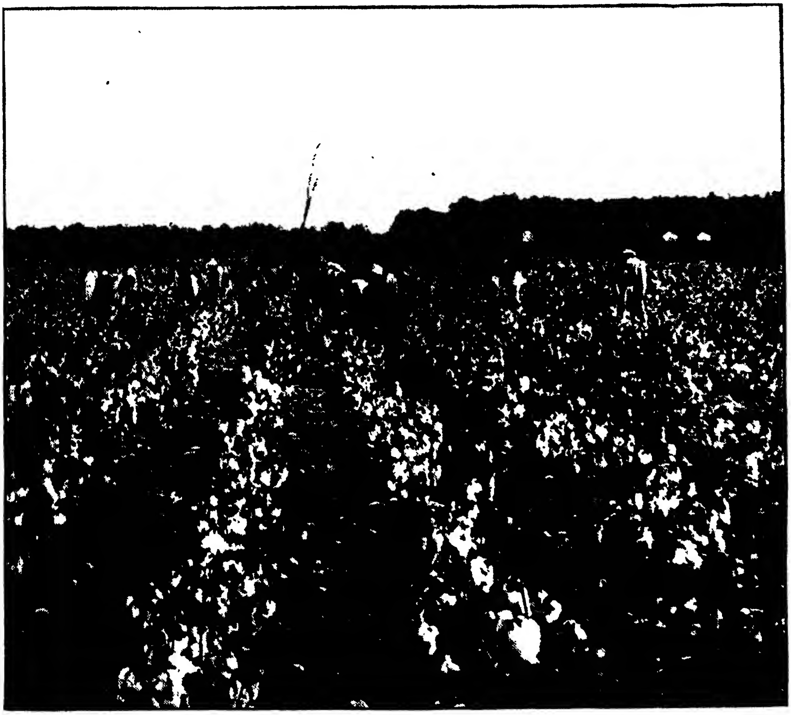
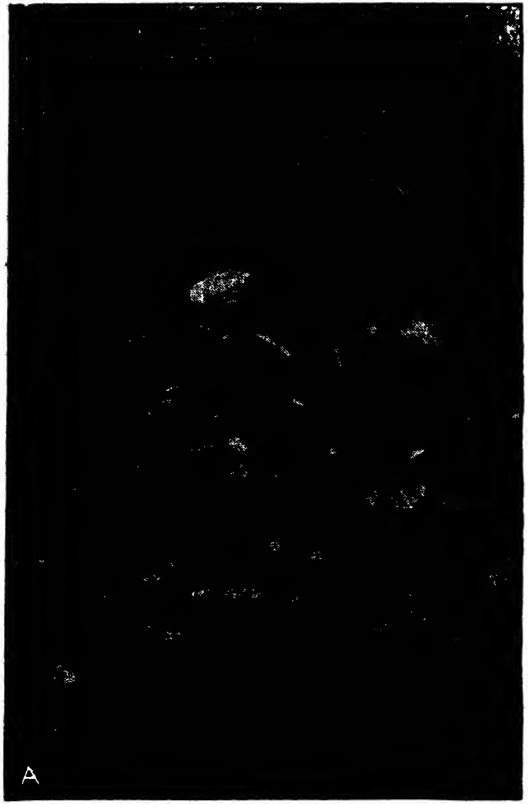


FIGURE 59. Norfolk fine sandy loam is a characteristic Yellow Podzolic soil, responsive to management, and adapted to cotton. A view near Winterville, North Carolina.



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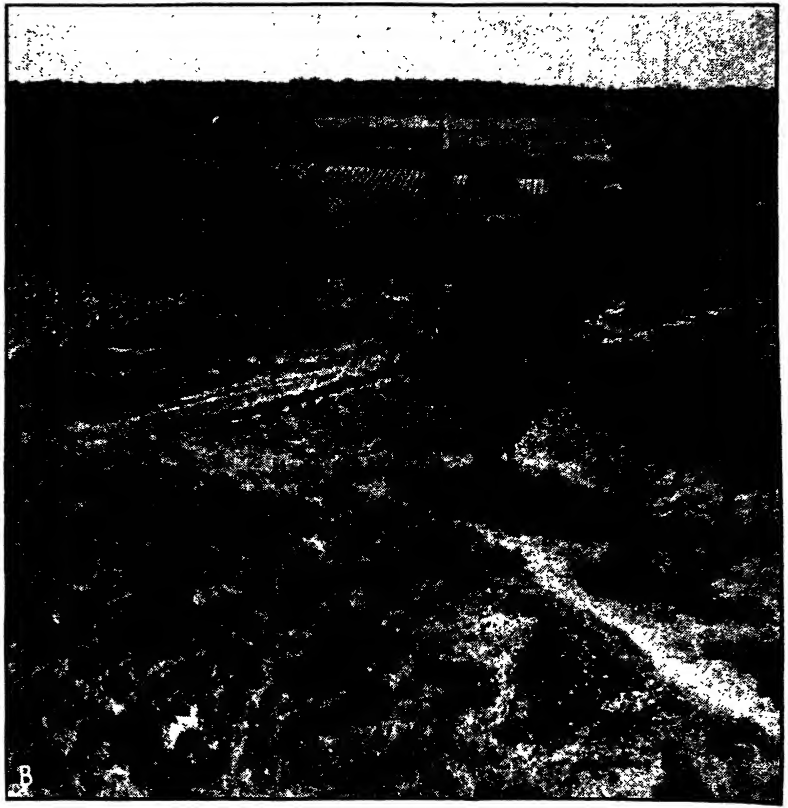

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phosphorus, in addition to lime, is necessary for good crop yields.

Among the Yellow Podzolic soils, is one series very well known throughout the broad coastal plain from Norfolk, Virginia, all the way around to east Texas, the Norfolk series, that illustrates this point well (Figure 59). Naturally the Norfolk soils are acid and infertile, but they have good structure. With lime, complete fertilization, and well planned rotations, including the legumes, excellent crops may be grown. Without these treatments yields are low. Such soils are said to be low in fertility but very responsive to management, and hence productive.

The Red Podzolic soils are somewhat more fertile than the Yellow Podzolic soils, especially those developed from high grade limestone rocks. They may be low in nitrogen, but this can be supplied, in large part by growing legumes in the rotation of crops. Usually, but not always, there is a fair supply of potassium, especially where considerable livestock is grown and the residues are returned to the soil. Lime and phosphate are usually required. A few soils in this group and some in the Gray-Brown Podzolic group are developed from limestones very rich in phosphorus and the soils are rich in phosphorus, like those of the famous Blue Grass region of Kentucky and the Central Basin of Tennessee. But these soils are unusual. Most podzolic soils are low in phosphorus and, sooner or later, need a fertilizer containing this element for good yields of healthy food crops.

In the Mediterranean regions there is another lateritic

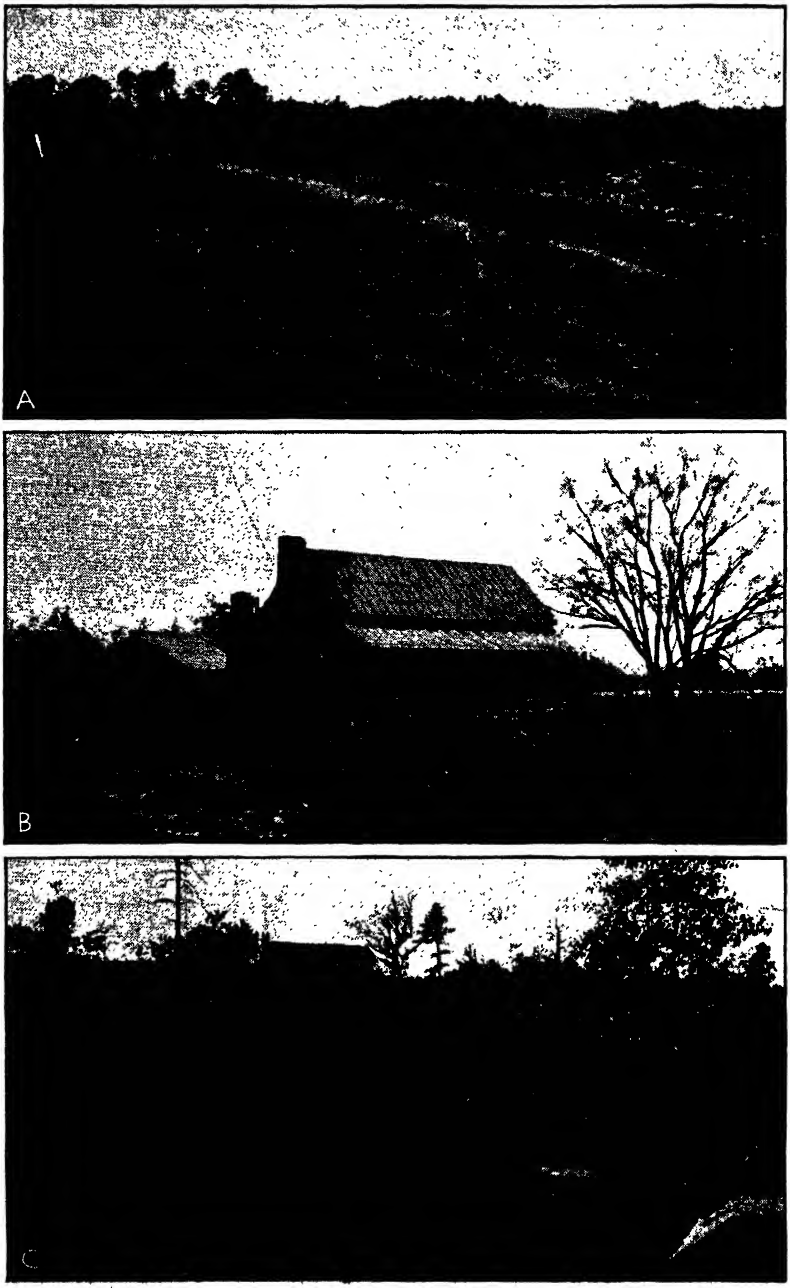
FIGURE 60. (A) Profile of Terra Rossa soil near Grasse in southern France. (B) A characteristic landscape on Terra Rossa near Avignon, France. These red soils are developed from hard limestone in the Mediterranean climate.

FIGURE 61. Grapes on irrigated Alluvial soils near Avignon in southern France. Note the windbreak to protect the grapes.

soil, the Terra Rossa, intermediate between the Gray-Brown Podzolic and the Laterite, developed over hard limestone, or from the deposits of weathered hard limestone. These soils are friable and relatively permeable to water, strikingly red in color, and slightly alkaline in reaction, *even in the surface.* They are developed in warm-temperature regions under a thin stand of forest growth where summers are hot and dry and winters are mild and moist.

None of these soils is found in the United States, although they are important in the countries around the Mediterranean Sea and in other places having similar climate, rocks, and vegetation. They are used especially for grapes and olives and a wide variety of subsistence crops, including grain, mostly on small farms (Figure 60). Associated with them are important areas of Alluvial soils, intensively cultivated (Figure 61). The general region occupied by these soils is broken with stony hills, patches of Rendzina on soft limestones, and weakly podzolic soils on other rocks. Small areas of Chernozem or Reddish-Chestnut soils are frequently found near the margins or in small valleys.

Among all lateritic soils, including the Red and Yellow Podzolic and Laterite soils especially, the abundant iron and aluminum compounds that have accumulated during weathering tend to "fix" the phosphorus and hold it in forms unavailable to plants. Thus even when phosphorus fertilizers are added, they may be fixed by the soil and made partly or almost wholly unavailable to plants. This problem is very serious in many soils in southern United States and no good method is known for overcoming it, although scientists have been studying it for some time. For crops planted in rows, like corn, potatoes, or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cotton, the fertilizer is placed in drills near the seed so it only comes into contact with a little soil, and thus only a little is fixed. But for close-growing crops like grass or wheat this method cannot be used. The problem is even greater with soils already eroded because the B horizon, in which these fixing compounds have been somewhat concentrated, is exposed and has become the new surface soil in which the fertilizers are placed.

The sloping soils in southern United States offer a serious problem of erosion control, or rather water control (Figure 62). Because of economic conditions—the general system of tenancy and the need of the individual farmer for immediate cash—there has been a tendency for farmers to grow too large a proportion of clean cultivated crops, like corn and cotton, even on these erosive soils. Already there has been a great deal of harmful erosion. These trends are now being changed somewhat, but very slowly. The large population on the land and their need for immediate income increases the difficulty of the problem. The problem cannot be treated from the simple point of view of soil erosion control, but must be attacked rather from the point of view of land management, of fitting the cropping practices to the soil so as to avoid the excessive run-off. First of all this means healthy vegetation with a large proportion of legumes and grasses. The soils must be supplied with lime and phosphate, and any other necessary fertilizer, although these two are most generally needed. In many places the cultivated crops are alternated with the close-growing crops in narrow

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FIGURE 62. Views in the region of Red Podzolic soils. (A) Where properly fertilized and terraced these soils are among the most productive in the world for cotton. (B) A cotton farmer's home. (C) Declining fertility and abandonment frequently lead to erosion.

strips running around the hills on the contour[1] so the water will not rush down the hill rapidly as when the entire slope is barren or in row crops. Terraces, essentially small smooth ridges, are also built on the hillsides to guide the water off the soil slowly. Terraces can be used successfully only where the soil is deep and relatively pervious to water. More will be said about these practices later, but it is well to remember that the principal control of run-off is growing vegetation and the plants must be strong and healthy. Thus for the podzolic soils—all podzolic soils and the Red and Yellow Podzolic soils in particular—the control of run-off and erosion means well balanced farms with cropping practices adapted to the particular soil conditions. This involves many, many considerations of which lime for acid soils, phosphate fertilizers, and crop rotations with grasses and legumes, are the most important.

The present low productivity and evidences of soil depletion in southern United States, as in other places where such conditions are found, is by no means entirely a result of original soil conditions and the climate. It is more a result of wrong use. The South developed many large plantations for tobacco and cotton production during colonial times. Slaves were brought in as field laborers. Cotton was well adapted to the soils and assumed a very important rôle. Cotton began to be grown on a large scale, especially with the development of the cotton gin at the end of the 18th century. Great improvements in spinning also increased the demand. King cotton was

[1] A contour is an imaginary line connecting all points of equal elevation. It is at right angles to the line of slope. If slopes were flattened and straight, like the roof of a shed, contours would be straight, but instead they are curved and winding. A terrace or irrigation ditch is made along the hillside at a slight angle to the contour so the water will flow slowly.

said to dominate the agriculture. The economy of the South depended upon exporting cotton to Europe and taking goods in exchange. Meanwhile in the North there were more family-sized, diversified farms. Early the North began to develop manufacturing. This development proceeded very rapidly with the growth of spinning about the same time as the cotton gin came into use. The northern manufacturers demanded tariffs against European goods, thus putting a handicap against the southern trade.

The two economies, the one on the Red and Yellow Podzolic soils and the one on the Gray-Brown Podzolic soils, came into serious conflict (see map in Figure 21). This fundamental issue and other differences, including the matter of slavery, led to the Civil War, a terrible calamity for the whole Nation and for the South in particular. The war and its equally unfortunate aftermath took an enormous toll of the South. Tenant farmers and share-croppers followed as the principal farmers of much of the region. Whatever the merits of plantation farming, of the Civil War, and of the period of reconstruction that followed, we are in no way concerned here. But the result was a shaken agriculture—many, many, very poor farmers that have had a hard struggle to make ends meet.

New practices, that take capital and require a delayed income are hard for many of these farmers to adopt. A shift toward more diversified farming with more livestock is essential. It is coming, must come, but at best it will come slowly. It must be remembered how important electric power, transportation facilities, farm credit, stability of prices, and secure tenure for the farmer are to this attainment of secure production and good soil management. The physical problem of good farm management,

difficult as it may be, is not nearly so difficult as the problem of social adjustments necessary to make good farming possible in this region of a growing population, where more subsistence crops of good quality and additional economic opportunities are urgently needed.

11.

MEN USE THE SOIL

EARLY man was a ranging nomad, constantly moving from place to place. He was keenly distrustful, always watching, and prepared for conflict. He took the land as he found it. The nomad lived as an exploiter with no effort to alter the soil or help make it produce. With the birth of the first agriculture there came the first civilization. There was an enormous change in man's relationship to the soil; he began to work with nature, not to steal but to sow. Fundamentally, the farmer became a conservationist. As farmer, man himself became attached to place, became firmly rooted to the soil that he tilled and that supported him. He learned to adapt himself to the physical conditions around him—to the seasons and the soil.

As agriculture developed in the various parts of the world, distinctions, differences arose. Men learned through experience that some things would work and that others wouldn't. More or less unconsciously they learned these things through living on the land. Each generation passed this knowledge down to the next. Of course, the whole culture of a people is not determined by soil alone. Besides farmers there are traders, miners, and craftsmen of various sorts whose work and prosperity depends upon the location of streams, of minerals, and of forests. Then, most groups come into contact with other

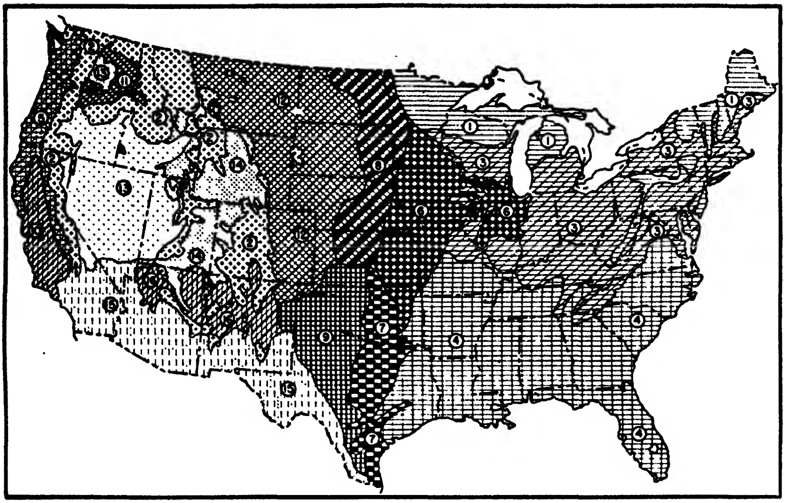

FIGURE 63. Broad associations of great soil groups in the United States. Each area shown on this map includes several soils which, taken together, make up a distinctive pattern, or broad landscape. Although the boundaries between the areas are drawn on the basis of differences in soil patterns, it is obvious that they also coincide with differences in relief, native vegetation, or climate that influence the soil. More important, it will be noted that these areas have fairly distinct types of farming and of rural community organization, growing out of the soil conditions, including the climate, vegetation, and relief associated with each soil type. Important local differences within each area exist, partly as a reflection of special soil conditions and partly because of original differences, some of which persist, among the people who settled on the soils. Thus these regions may be thought of as broad rural cultural areas, less sharply defined and less distinct than the soil groups, because men are not exclusively children of their immediate environment.

The regions are described briefly and in parentheses are given the names of the broad groups of soils that compose them. The location of these groups is shown in more detail on the large soil map in figure 21 and the groups are described in Appendix II.

1. **Light colored leached soils of the northern forested regions with included swamps and stony soils. (Mostly Podzols with associated Lithosols, Bog, and Half-Bog soils.)**
2. **Leached soils of the high mountains with thin soils on the slopes and areas of various soils in the adjacent valleys. (Various podzolic soils, some Alpine Meadow, much Lithosol, and small irregular areas of Brown, Chestnut, Chernozem, and Prairie soils.)**
3. **Grayish-brown and brown leached soils of temperate forested regions with some poorly drained soils and, especially in the southwestern portion, soils with claypans. (Mostly Gray-Brown Podzolic with Brown Podzolic soils in eastern part, Planosols, especially in southwestern part, and Wiesenböden, Bog, Half-Bog, and Alluvial soils.)**
4. **Red and yellow leached soils of the warm-temperate forested regions with poorly drained soils of the coastal plains and alluvial soils of the lower Mississippi Valley. (Mostly Red and Yellow**

groups. Trade develops and ideas are exchanged. Certain special groups develop that cut across all others, such as the priesthood and the military. The things we call culture and civilization are very complex. There are many factors that contribute, each interacting with one another.

Yet the character of the soil has had an influence on the development of culture. Men adopted certain practices, certain modes of living, and certain ideas because of what they must do to make a livelihood from the soil. In turn, the culture colored their notions of the soil. Frequently it has happened that great cultures have developed and civilizations flourished, only to lose their adjustment to the soil. They either did not make necessary changes, or made changes that they shouldn't have made, with resulting failure to attain secure production from the soil. Many times wars, disease, or internal revolutions have brought such pressure upon the farmers that they would

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Podzolic soils with Ground-Water Podzol, especially in southeastern part, Bog, Half-Bog, Alluvial soils, and some Rendzina and Wiesenböden.)

5. **Red and gravish-brown leached soils of the northwest forested region with much hilly or stony soils and some alluvial soils. (Red and Gray-Brown Podzolic soils, and Lithosols with some Planosols, Alluvial soils, and other soils.)**
6. **Dark colored soils of relatively humid temperate grasslands with some nearly black poorly drained soils and some light colored soils on steep slopes. (Mostly Prairie soils with some Wiesenböden, Planosols, Gray-Brown Podzolic, and Alluvial soils.)**
7. **Dark reddish-brown soils of relatively humid warm-temperate grasslands with nearly level black soils on marls and spots of light-colored leached soils. (Reddish-Prairie, Rendzina, and Yellow Podzolic soils with some Alluvial soils and Wiesenböden.)**
8. **Dark-colored soils of subhumid temperate grasslands. (Mostly Chernozem.)**
9. **Dark reddish-brown soils of subhumid warm-temperate grasslands with some hilly soils. (Mostly Reddish-Chestnut soils with some Lithosols.)**
10. **Dark-colored to light-brown soils of the California valley and coastal mountains. (Chernozem, Prairie, Chestnut, Reddish-Chestnut, Desert, and Alluvial soils, Lithosols, Planosols, etc.)**
11. **Dark-colored to light-brown soils of the northwest (Palouse) region. (Chernozem, Prairie, Chestnut, and Brown soils, with some Lithosol.)**
12. **Brown to dark-brown soils of the semiarid grasslands with some hilly soils, sandy soils and "badlands." (Mostly Chestnut and Brown soils with some Lithosol, Dry Sands, and other soils.)**
13. **Grayish soils of the arid west (and northwest) with soils of arid and semiarid mountains and mountain slopes. (Mostly Sierozem or Gray Desert soils with much Lithosol and some Brown Chestnut, and Alluvial soils.)**
14. **Grayish soils of the arid and semiarid intermountain plateaus and valleys. (Mostly Sierozem or Gray Desert soils and Brown soils with some Lithosol and other soils.)**
15. **Reddish soils of the semiarid to arid southwest. (Red Desert, Reddish-Brown, and Non-Calcic Brown soils, with much Lithosol.)**
16. **Brown to reddish-brown soils of semiarid southern high mountain plateaus and valleys. (Mostly Brown and Chestnut soils with much Lithosol and some Desert and other soils.)**

not or could not follow good practices. Rural poverty or soil depletion, or both, have been the result.

A great conflict always arises when men move from one soil region (Figure 63) to another, a conflict between the old traditions and the demands of the new soil. When the English colonists came to America they found the soils, especially of the northern colonies, much like those at home. Drastic changes in methods were not necessary. But later drastic changes were required when people moved from the podzolic soils of eastern United States to the Chernozem, Chestnut, and Brown soils of the Great Plains. English common law worked better in New England than in the West. The period of so-called lawlessness—the period of the six-gun and the bad cowboy—was a period of adjustment to the new soils. To some degree the Civil War was a revolution of southern farmers against the economic policies of the North. In both places, in the South and in the Great Plains, there is enough poverty and insecurity among rural folk, and soil erosion, to furnish evidence that a satisfactory adjustment between the people and the soil has not been reached.

Not only are there differences from place to place, but even in the same place, on the same soil, the methods of the farmer must change with changes in the cultural world about him. During the past 200 years these changes in Europe and the United States have been great and far-reaching. During this time science has risen from humble beginning to become a tremendous force. Home industries have given way to mass production in cities. Great systems of transportation have been built. Large corporations have arisen. The whole cultural life of the farmer has broadened and quickened. A hundred years ago the Illinois farmer lived on the frontier. He was a

citizen in a small community of people much like himself; now he has become a citizen of the world. In colonial times the farm was a home, furnishing nearly everything the family needed; now it is a business dependent upon the caprices of politics and economics. All these changes have caused great changes in the use of the soil. Some have been able to make the adjustments, others have not.

Although science has led to enormous changes in industry and commerce it has also been of great service to agriculture. The early farmer depended upon simple trial-and-error, and progress in methods was very slow, indeed so slow that untold suffering and despair accompanied them. Science permits us to make predictions more accurately; in fact, the making of predictions is the fundamental purpose of science. The Roman farmer used lime because some one had found it helpful. The modern farmer uses definite amounts of lime on certain soils to correct acidity. Both practices were the result of observation, the one roughly approximate and wasteful, the other specific. Many times observations were not investigated and gave rise to false ideas, such as the virtue of planting crops in certain periods of the moon, devices for making rain, the use of charms for encouraging plant growth, and so on. Through scientific researches better plants and animals have been developed that give better yields or widen the farmer's choices, or both. Fertilizers are now made to supplement deficiencies of plant nutrients in the soil. Farm machinery has been made that greatly increases the work accomplished by farmers. (As in industry, the development of machinery has contributed to rural unemployment.) Thus modern farmers have many more choices and many more devices for us-

ing the soil than early farmers. Even if their problems are not less, they are, at least, very different, even on the same soil.

Until comparatively recent times farmers learned what crops their soils would produce and the methods to employ from their experience, and that of their fathers and grandfathers before them. Agriculture was highly traditional. Even for a time after 1900, many farmers looked with some contempt upon the agricultural scientists at the experimental stations. Book-farmers they called them. Most of that feeling has gone. Farmers are using the results of science to an unusual degree. But, of course, these results of scientific research with new plants and new methods of tillage, fertilization, and other techniques must be related to definite soil conditions—definite soil types—just as the experience the farmer uses as a guide must be. Even a good practice for one soil may be ruinous for the next one. It is for this reason that accurate soil maps are so essential for assembling the results of scientific research and extending them to farmers.

When the soil is used by man, it is used in its total environment, both physical and cultural. One cannot say how much of the growth of a crop is due to soil and how much to climate. Nor can one determine exactly the effect of organic matter, of slope, of phosphate content, or of any other single characteristic of the soil by itself. The effect of any one of these depends upon the other factors in the whole combination. If all the factors are constant, or essentially so, except one, such as slope or acidity, the influence that this one has may be determined *for that particular combination*—that particular soil type. In some other combination—some other soil type—the relationship may be entirely different. If a group of soils in

New York are suitable for alfalfa as far as slope, stoniness, depth, structure, nutrient supply, and so on are concerned, except that they are too acid, small differences in acidity will be very important. The application of lime necessary for good alfalfa might vary from 1 to 3 tons of ground limestone per acre. It is important to know exactly what is needed, 1 ton, 2 tons, or 3 tons. But if these soils were too stony, let us say, for alfalfa, these same differences in acidity might have little significance in forest management.

In nature, the soil and the plants growing on it represent the sum total of the influences of the past and a balance among the factors in the present environment. Early man lived on what he found. Civilized man brings about changes, and attempts to guide these natural processes of plant growth through special channels in order to satisfy his wants. As soon as anything about the soil is changed, the soil itself changes. The work that man does in changing the natural conditions—the plowing, fertilizing, planting, and so on—is repaid to him by the greater growth of desirable plants. The intelligent farmer uses those practices and plants those crops that (1) give him the greatest return for the labor and materials used, and (2) leave the soil in the best condition for future crops. Sometimes there is a conflict between these two purposes. That is, a crop of corn may be more valuable than a crop of hay, but after growing the hay, the soil may be more productive for a crop of corn than after corn has been grown.

If all farmers were intelligent, ambitious, free of prejudices, thrifty, free to make their own choices, free of outside pressures, gave thought to their future welfare, and were well informed about the precise effect of all possible

practices on their particular soil, likely there would be no such conflicts. If only the immediate production—the crops this year—is considered there is very often a serious conflict. A farmer on sloping land in the South, for example, may make the most money for the year immediately ahead by growing cultivated crops like cotton, corn, and tobacco even though there is a decrease in organic matter, erosion, and a decline in productivity. A carefully planned group of crops, including hay and pasture on the erosive areas, the use of lime and phosphate where needed, the construction of terraces where helpful, and legumes on part of the land, might give a lower income the first year but improve the soil and mean better yields later. There are few if any places where there is any conflict between those practices that give the greatest income over a period of 10 to 20 years and those that maintain soil productivity.

A farmer with little money and great need may find it almost impossible to adopt this long-time point of view. He needs money so badly that he sacrifices soil productivity for immediate cash income. Then the following year the situation is worse. Thus soil depletion becomes a vicious circle. The final result is a bankrupt farmer with poor soil. Many farmers have had the will and the ability to take the other course—to plan their practices to build up the soil—and have good farms with soil much more productive than when they started. There are many such farms in Western Europe, in England, and in our own country, especially on the good Gray-Brown Podzolic soils of Pennsylvania, Maryland, and western Virginia, for example.

Some farmers take the "low road" from choice. They may have some other main interest than building a home

on the land, or preserving its productivity, like the "suitcase" farmer who lives in town most of the time. Many don't know what to do, especially those whose fathers followed poor practices. They may work hard, but to little avail. There are many, very many, who can't take the "high road"—the road to secure production—because of a lack of money to establish flocks and herds, buy lime and fertilizer, seed legumes and get started. To go from the "low road" to the "high road" means delayed income. If there are high taxes and other absolutely necessary expenses to pay, it is impossible for many.

Worst of all, many farmers are on land that does not belong to them and they have no desire to improve it when they may be unable to reap the reward. It isn't necessary that a farmer own the land he tills outright, but it is necessary that he have some security that he won't be removed without notice, and that when he does move off the farm he will be paid for the improvements he has made. The most important sign of agricultural decline in any country is a large percentage of landless, poor, insecure farmers, whether slaves or not. The large number of such agricultural people in the United States is itself a great problem. More important still is the greater problem their presence indicates—that some fundamental adjustments in their relationship to the soil must be made.

The great growth of business has required adjustments that some farmers have been unable to make. A few hundred years ago, in colonial times in the United States, the farm was a home. It furnished nearly everything the family needed. A large part of the things used by the family were made in the home from raw materials raised on the farm or obtained without cash expense. Land values were low, taxes were low, and few things were pur-

chased. Although money was scarce, not much was needed. Periods of low prices were unwelcome, but they could be withstood for people needed to buy so little. Since that time farming has become more specialized. The farmer buys all his clothing, his lumber, machinery, automobiles, and hundreds of things that he once produced for himself or did without. He could raise a horse and feed it on home grown feed. His transportation cost him little. Now he uses an automobile at great expense. Soil became land, and land is real estate.

Land values have risen. Taxes have risen. The roads for his city-made car, public schools, and all the other governmental services must be paid for with taxes. The modern farmer must have money, even if he leads the "simple life." Anyway very few want to leave the comforts that have come with modern science. But all this means the farmer is subject to the ups and downs of prices. Good land is not to be had cheaply. Many farmers of the last century and the first part of this took up cheap land, made their living, and had high valued land when they grew old. The farmer on high valued land cannot long endure low prices. He goes bankrupt. During the World War land values reached an enormous height, then prices suddenly fell. Taxes, costs of living, and other expenses remained high. Thousands of farmers went bankrupt. There was no new land to settle, no place for stranded people to go. Many of them piled up on the land, already overcrowded as far as the market for agricultural products was concerned. It became clear that some drastic measures would be needed—measures that would not have been necessary when people had new land to go to and were not so directly influenced by prices and money.

All this has served to focus attention on the soil and its use in this country. There is plenty of land in the United States for all our needs for a long time. But millions of acres—probably about 75 million acres—now being cultivated are too poor for cultivation by any known practice and return the farmer living wages for his labor. What of the people on these acres? Another larger acreage is good enough if it were used correctly, but farmers are using methods that give low income or lead to soil depletion, or both. By using good methods, methods already known, farmers in United States could probably increase their crop land from a little over 400 million acres to about 500 million acres, farm it safely, have a good labor income, and increase their total production by 50 percent if prices of their products kept to the average of 1920 to 1935. But, of course, there is no market for such an increased production; or is there one and they haven't found it? But the biggest problem is not the soil directly but the people on the soil. Soil must be used by good farmers to remain productive. The emphasis must always be on the people who care for the land, not directly on the land. A poverty-ridden people pass their suffering to the soil.

12.

SOILS FOR DIFFERENT CROPS

THE different associations or groups of plants that are found on the natural undisturbed soils, like the soils themselves, are the result of many factors. Although the soil owes much of its character to the influence of plants, of course it has, in turn, an influence on the plant association: the plant associations and the soils have evolved together. One group of plants may first take root in a young soil, and gradually new plants come in and others drop out as the soil becomes older, passing through several stages to what is called the "climax" vegetation. If the native plants are destroyed by fire or by cultivation, an entirely different group may take root and many many years may be required for the climax type to appear. For example, many abandoned fields in eastern United States are taken over by pines, although the climax forest was hardwood. These pines may grow and gradually be replaced by other trees, and finally the hardwoods will come back again.

Although there is a very close relationship between native plant association and natural soil types, there are exceptions, especially with young soils and near the boundaries between soil types. Even in the natural landscape variations in weather conditions, resulting in droughts and floods, fires, and volcanic activities, change the plants and soils differently. As soon as man enters on

the land, great changes are brought about. Sometimes it is said that man has disturbed the "balance of nature." But, of course, things are influenced by man, whether he is thought of as a part of nature or outside of nature. It is easy for some people to become very poetic and emotional about this so-called "balance of nature" and how people should return to it, especially if they can look at it very comfortably from some secure place. Although this idea of balance in nature may be pleasant, it is not very useful and hardly accurate. In a strict sense nature is not in balance—never is. With intense competition among plants and animals (fang-and-claw fighting for existence) in a complex set of physical conditions, soil and plants do gradually approach a balance or a harmony but probably never reach it; conditions change and start the whole pattern in a slightly or greatly different direction.

If men are to have more than the simplest life of the simplest savages, they *must* disturb this so-called balance, they must change the natural plant cover to the plants most useful to them. Of course, these changes *may* have far-reaching results. New diseases and insects appear. The fire hazard in forests increases. Floods may be more troublesome. Man must devise techniques to counteract any bad influences of the techniques he uses in growing crops and making a living. In other words, he must think of himself as a part of the whole natural process and learn how best to live in it, to get what he needs without hazarding his future; in short, to control it. This he does better by adapting his methods to the conditions at hand than by going against the grain any more than necessary to accomplish his ends. But a complete return to nature is a return to savagery.

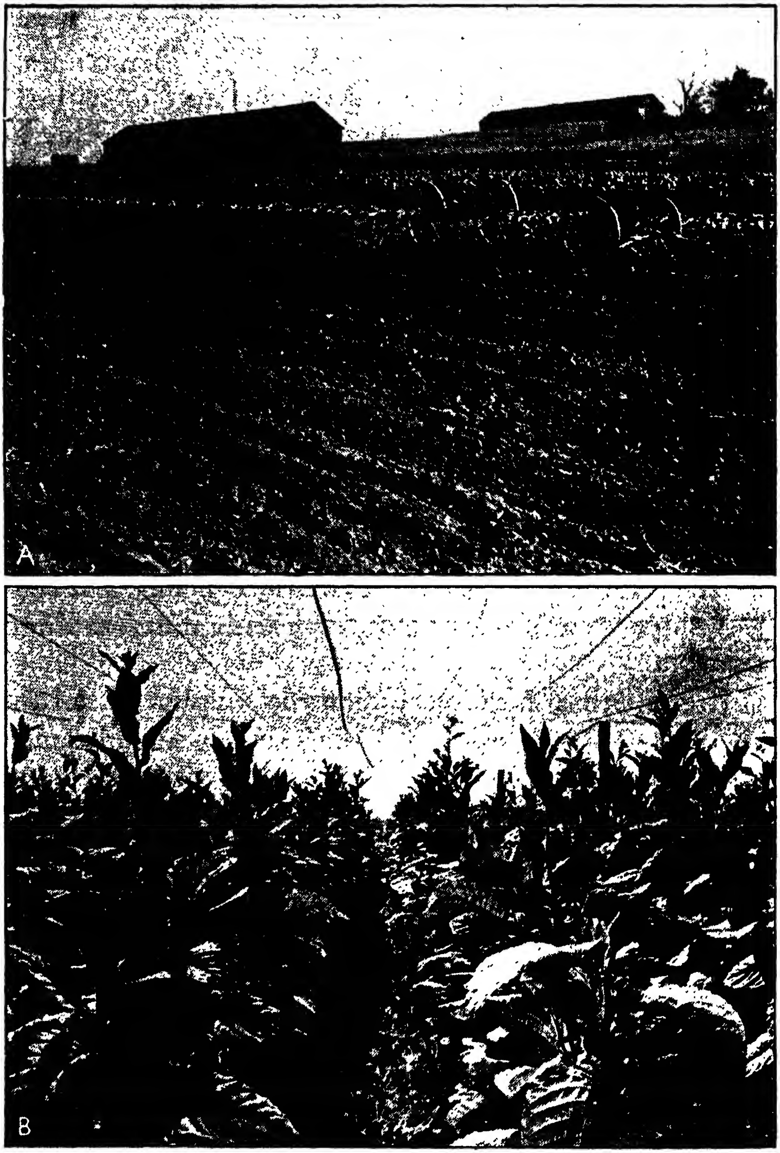


FIGURE 64. Tobacco is an important crop on the sandy, responsive Brown Podzolic soils of the Connecticut Valley. (A) General view, showing tobacco being harvested—drying barns in the background. (B) Choice tobacco is grown under "tents."

First of all, man gets food from the soil. Some foods are obtained directly from plants; but most foods and many other materials such as cloth, lumber, drugs, varnishes, and plastics are made from plant materials. Because of their usefulness the growth of certain plants is encouraged, like wheat, corn, cotton, and sugarcane. Through careful selection man has been able to extend the growth of some of these plants to many types of soil, increase the yield of the portions used, and improve their quality. This last point, the improvement of quality, especially of food plants, has been neglected. In the future much more emphasis upon the content of vitamins and necessary minerals in food plants can be expected. The selection of crops to be grown and the practices of husbandry will be directed more and more toward producing food crops of a quality required for good nutrition. But already an enormous amount has been done to improve native plants more in accordance with man's needs and taste.

As a very general principle, subject to several exceptions, it may be said that those plants grow best on any soils that are most like the native plants. Thus we expect tree fruits in forested regions and wheat in the grassland areas. As soon as man adopts such modifying techniques as fertilization and irrigation, he may grow a much wider range of crops than on a soil which has been only cleared and tilled (Figure 64). Tender plants may be grown in northern countries by being nursed in greenhouses in the spring and planted out in fields in summer. Thus, man changes both soils and plants in attempting an adjustment between his living and the soil. But the importance of selecting plants to suit the soil conditions, especially for

commercial production, is usually, though not always, paramount in making this adjustment.

For most crops there are some particular soils upon which each one will grow best in respect to the amount produced for the labor required. Corn, for example, grows best on the dark colored Prairie soils, like those of Iowa and Illinois. It also grows well on the rich alluvial soils along streams throughout the southern and middle eastern part of the country. But corn is grown on many, many soils in the humid and subhumid parts of the country, sometimes with very low yields. It is grown frequently on sloping lands in the South where the production of any cultivated crop leads to destructive soil erosion. By careful breeding and selection, varieties have been developed that can be grown on the Chernozem soils of eastern North Dakota and in the region of Podzol soils. Of course, yields are relatively low as compared to those on the Prairie soils, but satisfactory enough to encourage its growth. New practices for increasing yields of corn (or any other crop) also extend its production to other soils, upon which it had not been grown previously.[1]

The soils considered to be primarily adapted to wheat production are the black (Chernozem) and dark-brown (Chestnut) soils of the subhumid regions. This crop is also grown very widely, almost as widely as corn. It requires less work for production than corn. That is, an acre of good Prairie soil in Iowa or of good Gray-Brown

[1] It is partly for this reason that despite the great improvement in crops and farm practices through the application of science, average yields have risen little in the United States. Yields on the best farms have increased greatly but the crops have been extended to other soils where the yields are low even with the new practices or varieties yet where without them the crops could not be grown at all. Furthermore, many new practices have been designed to cut production costs. Yields per man-day of labor per acre have increased enormously in the United States as a result of scientific developments in agriculture.

Podzolic soil in Ohio will produce more dollars at ordinary prices in corn than in wheat, even though yields per acre of wheat are greater on these soils, well managed, than on the Chernozem soils. On the Chernozem and Chestnut soils yields of wheat are relatively low but little work is required per acre and this crop is more valuable in terms of labor income than any other crop that can be grown now on those soils. Also the wheat is of better quality. But on many soils where corn is a higher yielding crop than wheat, corn cannot be grown year after year without injury to the soil so wheat, or some other small grain, is grown a part of the time; and frequently clover is seeded in the grain to produce a crop the following year.

Hay is one of the most widely grown crops in the country, especially where there is a long winter season during which animals cannot graze. Before automobiles and trucks replaced horses in the cities, a great deal of hay was grown for sale in the open markets. A few farmers still grow hay primarily for sale, as some of those producing alfalfa under irrigation in the west, but mostly it is grown for use on the farm. Most soils can be kept productive only if hay and pasture crops, especially the legumes like alfalfa and clover, are grown a part of the time. Even though soils may be productive for either corn or wheat, most of them will not remain so unless seeded to the grasses part of the time. Thus farmers may grow hay partly to maintain soil productivity and partly to feed livestock that are also being fed corn. The amount of livestock must be adapted, therefore, to the crops grown, as well as the crops to the livestock.

Most farmers grow several crops each year, including some that may not be ideally adapted to their soil if con-

sidered singly but are properly included in a combination of crops and livestock that are well adapted to the land. One of the oldest crop rotations in the United States is one composed of these three crops we have been discussing—corn, wheat, and hay. A simple general farm in the Gray-Brown Podzolic soil region would be one with three main fields alternately devoted to these three crops with a permanent or semi-permanent pasture and a home garden and orchard. Oats may replace the wheat, and potatoes the corn, especially in the Podzol soil region further north. On the Red and Yellow Podzolic soils of the South cotton or tobacco may replace part of the corn.

Usually general farms are not so simple as this example with a three-year rotation. Where more feed grains are wanted, the rotation may consist of corn, oats, wheat, and clover. This fundamental rotation is one of the most important. Potatoes, beans, sugar beets, or tobacco may replace all or part of the corn, and barley or rye may be substituted for wheat. Another rotation may be corn, barley, and alfalfa for 3 or 4 years on a part of the fields.

On the Chernozem soils these rotations, with emphasis upon wheat, may be followed. On the soils of the Reddish-Chestnut group—the southern extension of the Chernozem—the grain sorghums replace the corn for feed and less clover is grown. In the Chestnut region there are only a limited number of crops that can be grown in the rotation with wheat. Here pastures are usually maintained permanently in separate fields or else for several years at a time. Wheat is commonly alternated with *fallow;* that is, the land is cultivated one year, enough to kill the weeds so that water may be stored in the soil for the next crop. When this is done care must be taken with the tillage to leave the soil roughened on

the surface or in small ridges on the contour in order to prevent soil blowing during dry periods and to encourage the entrance of water into the soil during rains.

There are instances where farmers grow the same crop on the land year after year or with only slight modifications, and the soil is maintained in productivity through large applications of fertilizers, through the growth of special crops like rye, soy beans, or cowpeas (green manuring crops) during periods when the main crop is not being grown and plowing them under while they are still green, and in other ways. Sugarcane has been grown almost continuously on many soils in the tropics for many many years. Tree fruits, olives, grapes, rubber, and similar crops are grown on the soil for many years at a time. Cotton or corn is often grown almost continuously on Alluvial soils, especially under irrigation, but such a practice cannot be maintained for very many years without soil deterioration unless fertilizers are used. Even some Alluvial soils must be devoted to grasses a part of the time if good soil structure is maintained.

In hilly regions where most of the soils are strongly sloping it may be better to grow corn continuously on the small strips of smooth alluvial soils than to follow rotations and have corn on the sloping soils part of the time where the erosion hazard is great. If the hilly soils are rather shallow over rock they cannot be terraced successfully and should be devoted to close-growing crops because if a strong rain happens to come in the summer when the land is clean-cultivated there is certain to be serious erosion. Grain to feed livestock grazed on the hilly soils can be grown as corn on the alluvial soils, but complete fertilizers will be required, including nitrogen. Using nitrogen fertilizer instead of legumes for getting nitrogen

in the soil for the corn and thus keeping corn off the erosive soil is an example of fertilizing one soil type to prevent erosion on another.

When land is cheap in relation to the net value of crops and can be bought or leased by anyone with money, one frequently finds single crops or very similar crops year after year, such as sugar beets, cotton, wheat, et cetera. Such cropping practices usually lead to soil depletion. Ultimately some system of crop rotations, with grass crops and livestock, is usually adopted, at least by people of European stock. There are exceptions to be sure, like the intensive fruit and vegetable farms of Florida, near large cities, and in the irrigated regions of Texas and California. There are many instances, as in China and Japan, where rice may be grown as the main crop under special management, without much alternation with other crops. Sugarcane and other crops in tropical countries are often grown continuously on plantations. Sugarcane has been grown continuously on some soils in Puerto Rico for over 300 years.

Usually, single crop agriculture has failed either to return a good living to the laborer on the land or to maintain the productivity of the soil, or both. There are many reasons besides the maintenance of soil productivity why a combination of crops and livestock returns a more secure income and provides a better living to the farmer than single crops. Even where the soil is very productive and not easily injured, single-crop farming usually means a poor living for the laborers, for those who do the work, even if not for the owners. If the price of one crop, for some reason, goes down to very low levels for a long time the farmer may be ruined. One-crop farmers may be rich one year and poverty stricken the next. Insects or dis-

eases may ruin one crop. Labor is necessary only at certain times in one-crop farming and then during other periods there is nothing to do, as in many of the extremely specialized areas of California. When growing only one crop very little of the family living can be had from the farm. With a combination of crops there is a more balanced use of labor and a more balanced income.

For a permanent and secure agriculture, attention must be directed toward fitting a combination of crops and livestock to a combination of soil types on each farm (see Figure 80). Each soil favors the growth of a few crops, but can produce several others. On most soils a combination of crops grows better than one or two year after year. Each crop grows best on certain soils but will grow well or fairly well on many soils. Although the Chernozem soils may always produce much wheat, the Prairie soils much corn, and the Red Podzolic soils much cotton, as agriculture becomes more stabilized in America, most small and medium-sized farms will have a wider range of crops with less specialization, especially in the humid regions. There are definite trends in this direction, but they must go much further if erosion is to be checked and rural poverty measurably reduced. Not only must the crops be more diversified, but farmers generally need to give more emphasis to the production of home foods—vegetables, fruits, and livestock products. The living of thousands of farm families could be greatly improved by growing more non-commercial crops for home use, even though yields are not large, thus conserving the cash income for those things that cannot be obtained from the soil. The growing of vegetables and fruits for home use could be greatly increased. Many soils that are entirely unsuitable for commercial produc-

tion of apples, grapes, pears, peaches, and numerous other crops will support varieties that will produce enough for the family.

During the period of rising agricultural prices, especially during the World War, many farms became overspecialized. Some have lost and many have not learned the simple skills necessary for producing food at home. A revival of these home skills would do much to lessen the burden of low prices when they come. It is not difficult to plan gardens so that much of the work may be done when other farm work is slack. A great deal of garden work can be done by little hands that need training at light and interesting tasks—and a garden with small plantings of a wide variety of vegetables, fruits, and flowers is as interesting as it is useful.

13.

PLOWING AND DIGGING

THE hoe and the plow are the oldest symbols of farming. The soil must be stirred to make it receptive for seeds and to encourage a good growth of the plants men want and, at the same time, prevent the growth of others. Kinds of corn or wheat that give good yields would not be able to compete with other plants—weeds, grasses, and trees—if left to themselves.

Some sort of plowing is one of the oldest arts. Even nomads stopped long enough to raise a few plants, and perhaps did some crude plowing. The practice of plowing fields regularly started with the change from nomadic life to agriculture. Primitive people depended upon hand tools, crude spades and hoes, to stir the soil. Today in some parts of the world, wheat is planted in soil made ready by hand tillage and is harvested by sickles. But the amount of grain is meagre in proportion to the labor required.

The first plows were little more than crooked sticks with one or more prongs digging into the soil, pulled by the workers, either men or women (Figure 65). In early times slaves were used for such work. Later, animals or men were harnessed to a pole, with a short stub of a branch on one end. By Roman times, wooden plows that somewhat resemble our modern plows, fitted with some metal parts in the places having the most wear, were

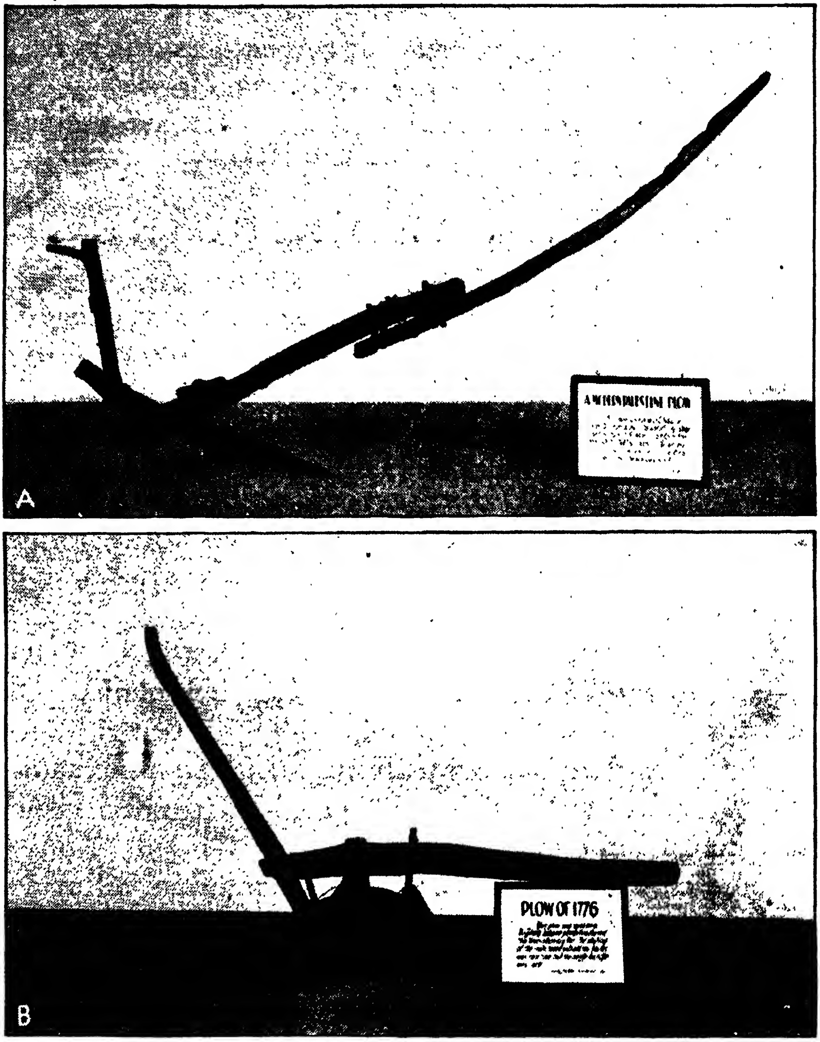


Figure 65. Some old plows. (A) A plow used until very recently (1930) in Palestine like those used many centuries B.C. (B) An early American plow in use during the period of the American Revolution. (Courtesy Bureau of Agricultural Chemistry and Engineering, U.S.D.A.)

pulled with oxen. Later wheels were added to the beam in order to control the depth of plowing more easily. During the long years between Roman and modern times, hundreds of different kinds of plows were used. Yet few really important improvements came until the rise of modern science, as applied to agriculture, and the easier manufacture of steel. Now, the use of steel plows is quite general throughout the United States, most of Europe, and other modern states. Yet very many people still cultivate the soil with crude tools.

The ordinary mold board plow seen in America turns over a regular slice of soil (Figure 66). In good plowing the soil is not turned bottom-side-up, but a little less than completely over. If a heavy sod were turned completely over, a dense mat of organic matter would be formed just under the surface layer, causing it to dry out easily. In plowing, it is better to have the organic matter somewhat mixed with the whole surface soil. In dry regions, as in the Great Plains, some of the organic matter needs to be left in the very surface, to protect the fine soil particles from blowing with the wind when dry.

Although one of the main purposes of tillage—plowing, harrowing, and cultivating—is to make a good soil structure for growing crops (the other is to kill weeds,·unwanted plants), the long-time effect may be to injure soil structure. When the soil has the best structure for ordinary crops, the separate grains of clay, silt, and sand are held together in soft or friable granules, or crumb-like aggregates. The particles are naturally grouped into these crumbs; they are not simply fragments of broken massive blocks. One may pulverize a coarsely cloddy soil into small broken pieces, but as soon as the soil is thoroughly wet again, the grains puddle, run together, and

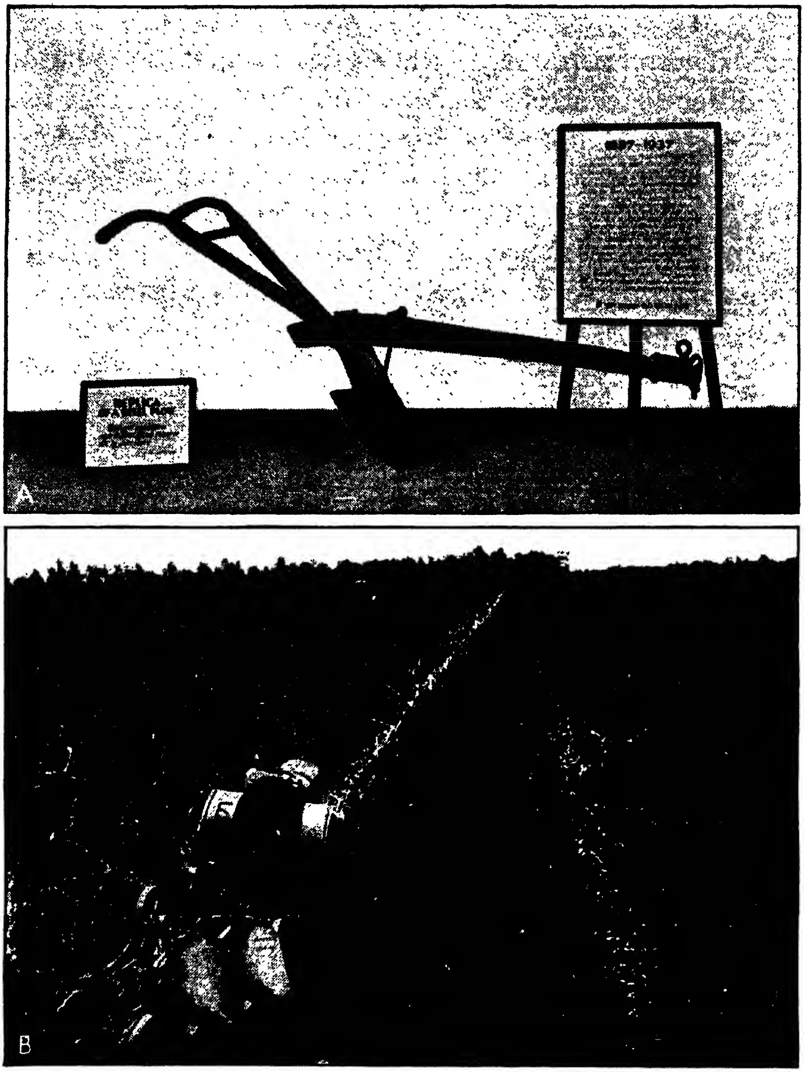


FIGURE 66. Early and modern steel plows. (A) An example of an early steel plow built in 1837. (B) A modern tractor plow with steel guards for turning under corn stalks. (Courtesy Bureau of Agricultural Chemistry and Engineering, U. S. D. A.)

the whole dries into a hard mass. Much plowing or stirring of the soil tends to shear the natural granules, destroy them, especially when the soil is very wet or very dry. As long as the Russian peasants simply scratched the surface of the black, granular soils of the steppes (Chernozem) with their crude tools the structure was little changed. But with the sudden coming of great tractor plows, many of them have plowed too often and at the wrong times, producing a hard, cloddy structure as a result.

Plowing in straight rows up and down the hills has increased the erosion hazard in many places, by providing little channels in which run-off may be concentrated and gullies begin. By plowing around the hills, or directly across the line of slope, the furrows become, in effect, tiny terraces to slow down the speed of the water and encourage its soaking into the soil beneath. On slopes of very erosive soils only strips are plowed, leaving strips between in grass (Figures 46 and 20). Soil moves down the slope with this method if furrows are always turned down hill. In some of the intensively cultivated fields of southern France, the furrow slices are turned down the hill, but enough soil from the foot of the hill is carted to the top to maintain a normal depth of soil there.

It is usually more convenient to plow, seed, and harvest in large rectangular fields. Such fields can be arranged where the soils are uniform, but if they vary in slope, in crop adaptability, or in tillage requirements, poor results may be obtained. The best practice for one soil type may cause erosion on another in the same field. Grain in one part of the field may be over-ripe, while the rest is still green. In much of the United States the land has been laid off in sections, one mile square. Many farms are square "forties" (forty acres), rectangular "eighties," or

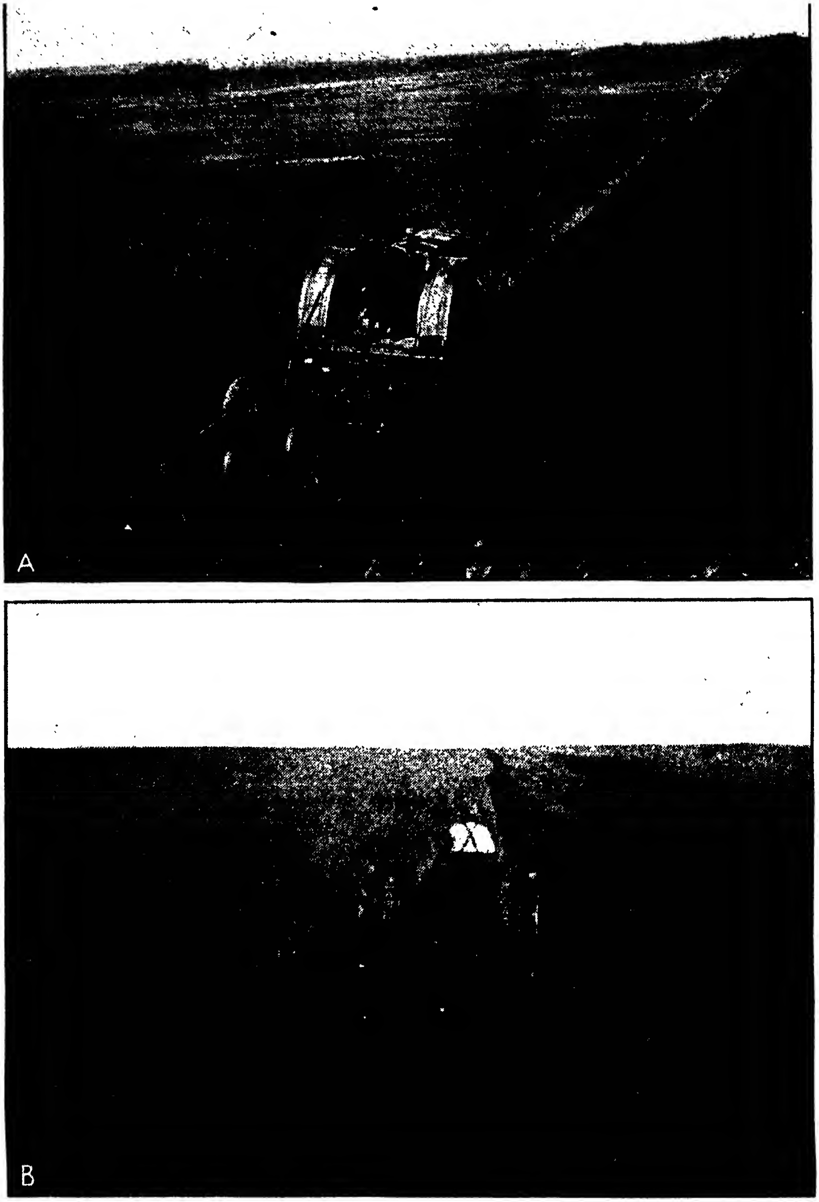


FIGURE 67. Modern tillage with tractors. (A) Plowing a dense sod. (B) The one-way disc for shallow plowing of wheat stubble. Where the soil is sloping these operations are conducted on the contour. (Courtesy Bureau of Agricultural Chemistry and Engineering, U.S.D.A.)

square quarter-sections. This had led to the building of roads and fences on these straight lines, regardless of soil conditions. Someone has said that we have too many "square fields in a round country."

Millions of acres of grassland have been plowed during the past 60 years in America. At first, the same methods were followed on these soils as farmers had used in the older settled regions of the United States and western Europe but with much more emphasis on cash crops. With the coming of gang plows and fast-moving tractors, large fields were plowed and seeded rapidly, sometimes all in one operation (Figure 67). New tools, such as large disc harrows, were made in order to speed up the process, especially during the World War.

Several years ago there came into use a new combination of practices, called "dry-farming." Land was plowed and cultivated during one year, or even two, without seeding, in order to store moisture for a crop the second or third year. Even now many fields have alternate wheat and fallow (cultivation without plants). It was thought that by keeping a thin surface layer of dry loose soil on the top, called a "dust mulch," the moisture could not rise to the surface by capillary action but would be conserved. This theory finds little acceptance today. It is rather the maintenance of the soil in condition to absorb the rainfall that falls, and the eradication of weeds, that conserve moisture. Too much cultivation tends to destroy the structure and especially does it encourage blowing of the soil. Thus the farmer is sometimes caught between these dangers of over-tillage to soil structure and the need to kill noxious weeds.

Recently tillage methods are being developed for the drier regions that will keep the surface soil somewhat

cloddy and filled with organic matter to protect the fine material from blowing, aid in the adsorption of the rain-water, and prevent weed growth. Especially in the southern dry regions, deep furrows are made with a lister along the contour which act as little terraces to catch water and also reduce the movement of blowing soil along the surface. As soil blows, there is a thin layer or film of rapidly moving soil particles on the very surface that starts other soil moving and kills tender plants. The ridging of the soil greatly checks this action. Sometimes the lister furrows are dammed at frequent intervals to make little basins to hold the water. This practice is especially helpful in dry regions where rains come as sharp showers.

On the whole, modern farmers in the United States still plow and cultivate too much. Many feel that there is some virtue in the dust-mulch theory and do not cultivate primarily to kill weeds. On many soils, especially those inclined to pack into hard masses, the use of heavy tractors over the land has added to the injury of structure. Yet the rapid methods of tillage make possible the tillage of the soil at more nearly the proper time than the older and slower methods. With the reduction in rates for electric power, many farm operations may be done in the future with electric power located at the margins of the fields and with machinery pulled with cables in order to avoid the use of heavy machinery on the soil.

Agricultural machinery is so expensive that plowing and tillage cannot be said to be especially cheap operations, although less man labor is required than formerly —much less. But the operations are more convenient now than formerly. More important as a cause of excessive tillage has been the emphasis upon cash crops—a nec-

essary emphasis as far as millions of individual farmers were concerned. As farms become more diversified, with more crop rotations including grasses and legumes, less tillage will be required and the problem of maintaining soil structure will be easier.

Deep plowing is advocated by someone from time to time. There are situations where it may be practicable. Where floods have left deposits of sand over fertile soil, sometimes enormous plows are used to turn it under and bring the old surface soil to the top. Some soils with hard subsoils are improved by "subsoiling"—not deep plowing, but an operation to break up the lower soil by pulling a deep bar or knife through it. In northern and eastern United States most farmers plow a slice about 6 to 8 inches thick. Usually plowing is shallower in the south. In the drier regions plowing is shallower, say about 5 to 7 inches in the Prairie soils of Iowa, 5 to 6 inches in the Chernozem soils of the eastern Dakotas, and 4 to 5 inches in the Chestnut soils further west.

Rather than "plow deep while sluggards sleep" one should plow well, at the proper time, and as little as possible, yet kill weeds, develop good seed beds, and make the soil receptive to rain water.

14.

FERTILIZERS AND LIME

FERTILIZERS of one sort or another have been used for thousands of years—long before the reasons for their good effects on soil productivity were known. Some American Indians followed the practice of putting a fish in the soil along with seeds of corn, as they possibly thought, to please the gods responsible for its growth. Anthropologists have uncovered a great many strange practices that were followed by primitive people to insure good yields. Most of these were in some way tied up with their religious rites and beliefs as the whole process of living and growing things was beyond their understanding. Not all of them were helpful by any means, even though they likely thought so. But some were based upon fortunate experiences and did prove useful, like the fertilization of corn with fish.

The most important fertilizer used by the ancients, and one still important today, is stable manure. In writing of the return of Odysseus, Homer mentions that he was recognized by his old faithful dog lying on a pile of manure "with which the thralls were want to manure the land." This practice is followed by many farmers today, fundamentally as it was then. The use of manure and crop residues is really a matter of returning to the soil part of the materials taken from it, both organic and mineral. On some livestock farms feed beyond that

grown on the farm may be purchased, and if the manure is properly conserved and applied, even more is returned to the soil than was removed. Similarly, plant nutrients may be transferred from permanent meadows to the arable soils of a farm through the manure.

Shortly after chemistry developed methods of analysis people thought that it would be easy to find out the fertilizer needs of a soil by drawing up a simple balance sheet. If the chemical composition of the crop, or crops, to be grown was known, as well as that of the soil, it was reasoned that one could see how many pounds of the various nutrient elements were needed for a crop and by dividing the amount in the soil by this figure find out how long the soil would last without fertilizers. Or better still, one could calculate the amount of each element to add to maintain the soil. Oh, were the matter that simple! But the theory has been found to fail badly, even though at first glance it seems to be so logical.

There are several reasons why it isn't even approximately true. Perhaps a look at some of these is as good a way as any of reminding ourselves of some of the things already said as they apply to this problem.

(1) The soil is dynamic, always changing, by no means a simple storage bin of plant nutrients. Many soils are each year losing a tiny bit of material from the surface through erosion; and new minerals are entering the soil from the bottom. Other soils are getting an addition to the top as dust from the air, or more important, sediment from occasional stream overflow, like the soils along the Nile, the Mississippi, and countless other streams, large and small.

(2) All ordinary soils are made up of a great mixture of minerals, varying in solubility and composition. These

are slowly becoming soluble but at different rates. A soil may contain a great deal of potassium, for example, but in only slightly soluble forms and, for good crops, may need potassium fertilizers; while other soils, having much less total potassium, may have enough available to the plants.

(3) Not only are there great differences in the relative availability of the same nutrients in different soils, but when fertilizers are added, especially phosphates, some soils "fix" them in forms relatively unavailable to plants while others do not. Thus acid soils relatively high in aluminum and iron compounds produced through intense weathering, like many of the lateritic soils in southern United States and in the tropics, are difficult to fertilize with phosphorus. In Hawaii, for example, large applications of phosphatic fertilizers are made frequently to the deep red lateritic soils used for sugarcane, but only a small part ever gets into the plants. Most of it is fixed in relatively insoluble forms by the soil.

(4) Some bacteria living in the soil can take nitrogen from the air and bring it into the composition of their bodies. When these die, the nitrogen is released in forms available to plants. Especially when legumes are grown, the nitrogen content of the soil may thus be considerably increased.

(5) Plants vary a great deal in their ability to extract nutrients from the soil. Although turnips contain relatively small amounts of potassium as compared to alfalfa, the latter is a "strong feeder" and can get ample supplies from minerals relatively unavailable for other plants like turnips. Some plants like alfalfa and sweet clover have relatively deep roots that may feed on a wide expanse of soil, while others are shallow rooted and nutrients in the lower horizon are unavailable to them.

(6) Many other factors besides the supply of plant nutrients influence the growth of plants, such as temperature, water supply, and the physical structure of the soil. If all the factors are favorable for the growth of a crop except the supply of one nutrient element, the plant may get along on a starvation diet in respect to that one. There is an old law of plant growth called "the law of the minimum"—that if one factor of growth is less favorable than the others, growth will be determined by the amount of that one. That is, if the amount of phosphorus were low, no increase in growth could be obtained until some of that nutrient was added. This "law" holds, however, only approximately within rather broad terms, not exactly. If many different plant nutrients are added singly to separate plots of a relatively infertile soil, several of them may give at least some increase in plant growth.

In natural soils that have reached a sort of balance with their environment, the losses from erosion, leaching, and removal by plants approximately balance the gains from new minerals and the activities of plants. When the plants are harvested this balance is upset. Instead of the plant tissue falling back on the soil to decay and return the minerals, it is removed. Unless new nutrients are added in more abundance, as along streams depositing rich films of sediment, some other way of compensating for those removed by plants may be necessary. Furthermore, many crop plants, such as corn, sugarcane, and wheat, require larger amounts of these than the native plants like spruces, pines, and sedges. Many soils may be deficient in one or more nutrients to begin with, especially those developed in humid regions, from the standpoint of good crop production.

Yet soils vary greatly in the supplies already at hand.

On some soils, fertilization with potassium or some other elements may never be necessary because of the large amounts already present in the soil and in the rock beneath—or at least not for many, many years. The same soil may need some other element after the removal of a few crops. Thus the planning of fertilizers is not a matter of replacing what the crops remove but one of adding to the soil what is necessary to supplement the supplies already in it that are available to plants for the particular crop or rotation of crops to be grown.

Lime is frequently added to soils, primarily to correct acidity, although it has other effects. Even though calcium, the main constituent of lime, and magnesium, another important constituent in some limestones (called dolomitic), are both plant nutrients, agricultural lime is not ordinarily thought of as a fertilizer, strictly, but as an amendment. Yet much of the good effect of lime on acid soils must be attributed to the calcium furnished the plants. Plants grown on very acid soils may be so deficient in calcium that they produce foods of poor quality—foods too low in calcium for good animal or human nutrition. The large amount of bone defects among people living on such soils can be largely attributed to diets poor in calcium and phosphorus. The improvement of these diets is partly a matter of food selection and partly a matter of soil improvement.

Most normal soils, as well as some others, developed under forest vegetation in humid regions, are too acid to grow the common agricultural crops well, and must have occasional treatments of lime. This even includes those developed from limestone, except soft limestones. Many soils in eastern United States are developed from weathered limestone or lime-containing parent materials, but

the true soil is nevertheless acid. Important exceptions are those developed from soft very calcareous materials [1] and those developed from any lime-containing material on slopes steep enough to have young, thin soils.

Plants vary in their tolerance of, or need for, acid soil conditions. A great many flowering plants, such as the rhododendrons and roses used as ornaments, grow best in fairly acid soils. Cranberries, blueberries, strawberries, and some others require an acid condition, although strawberries, for example, need some calcium and may need a little lime on extremely acid soils. Sugarcane, cotton, buckwheat, lespedeza, and many others will tolerate acidity, but will not grow well in extremely acid soils very low in calcium. Alfalfa, sweetclover, and several other clovers will not tolerate a very acid soil, although this varies with the soil. Common red clover will grow well on a medium acid Podzol soil in northern Maine or Wisconsin, but do very poorly on a Gray-Brown Podzolic soil of the same acidity in Ohio or Pennsylvania.

Those bacteria that are of most importance in changing the nitrogen in plant tissue to forms usable for most crops do not grow well in acid soils. The same is true for most of those that take nitrogen out of the air and ultimately make it available to plants. Thus one of the good effects of liming an acid soil is to favor these bacteria, as well as those that decompose organic matter to form humus most effectively.

[1] The intrazonal Rendzina soils developed under grasses in humid to semiarid regions and the Brown Forest soils developed under hardwood forests in humid temperate regions from soft very calcareous materials are not very acid in the solum. Except for the Rendzina soils of Alabama, Mississippi, and Texas, neither group is important in the United States, but both are important in western Europe. The so-called Terra Rossa soils of the Mediterranean region of southern Europe are developed from hard limestones under a relatively open forest in a wet-dry climate, but are not acid. (See Appendix II.)

Liming an acid soil also makes aluminum less soluble. Some soils contain enough soluble aluminum to be toxic to plants. It is thought by many that liming reduces somewhat the bad fixation, in relatively insoluble forms, of phosphates by aluminum and iron compounds. But on the other hand, liming reduces the solubility of manganese, iron, and some other elements. It has been found that over-liming soils, that is, applying more than an amount necessary to correct acidity, especially very acid, leached sandy soils, may cause serious deficiencies of iron, manganese, magnesium, and potassium. This depends also upon the relative needs of the crop. For example, pineapples are especially susceptible to deficiencies of soluble iron, tobacco of magnesium, pecans of zinc, and so on. Pineapples are so susceptible to a deficiency of iron and over-liming that as far back into a field as the wind carries the limy dust from a gravel road the plants may be yellow and sickly. Extreme over-liming may also depress the availability of phosphorus to plants.

Many, many soils in the humid, forested regions need lime for best crop growth, especially when some good legumes like alfalfa should be grown. Even the Romans used lime, and its use is a very old practice in England. Only during the past 120 years have people known why it was beneficial. Good soil tests to determine how much to use have been available for only a few years. The amount any soil needs depends upon the length of time it has been cultivated and how it has been handled as well as upon the original acidity and the crops to be grown. Each field should be tested in several places and the amount needed determined accurately for the different parts of it. For strongly acid soils, one usually uses about 1 to 2 tons of ground limestone for sandy soils, 2 to 4 tons

for silt loams, and 3 to 5 tons for silty clay loams relatively high in organic matter. But this depends upon whether the soil is acid for great depths or only in the surface horizons, what crops are to be grown, and so on. When potatoes are grown in the rotation, for example, one uses as little lime as possible for good crops because additions of it may favor the growth of the potato scab, a serious disease. Tobacco may be more susceptible to a disease of the roots unless the soil is acid, but the crop does poorly in extremely acid soil. On the other hand, bananas are more likely to get a serious wilt disease when growing on acid soils.

There are times when it is necessary to make the soil more acid, less alkaline. Some soils in semiarid regions are too alkaline for good crop growth. If these are drained well, calcium sulphate ($CaSO_4$) or plain flowers of sulphur may be added to reduce the alkalinity. If one wants to make soils that are nearly neutral or only slightly acid, more acid in order to grow flowers or trees that require an acid soil, sulphur can be used or occasional light applications of a common nitrogen fertilizer, ammonium sulphate. Sometimes people use a little vinegar on a nonacid soil like a Chernozem in order to grow garden flowers that require an acid soil.

On the great Hungarian Plain there are spots of alkaline, sticky soil, now called Solonetz, that centuries ago the peasants learned to improve by digging up the deep subsoil and spreading it out on the surface. This material was the horizon of calcium sulphate accumulation that lies just under the calcium carbonate horizon of soils in semiarid regions (Figure 12). These people had discovered, probably by chance, a practice that was not explained for many years, and had passed it on to their sons.

Now, of course, they use prepared chemicals. As with many other agricultural practices, the contribution of science has been to explain an old practice, perfect it, and make a more precise use of it possible.

Although the use of lime to decrease acidity (and of other substances to increase it) is not strictly fertilization the two practices are closely related. The use of phosphate fertilizer on an acid soil is less effective than upon one that has been properly limed in advance. More nitrogen will be made available to plants by microorganisms in a soil properly limed than in an acid soil.

Now a few of the elements commonly supplied by fertilizers will be discussed briefly.

Nitrogen is the most commonly deficient plant nutrient in arable soils, considering those of the whole world. Generally, those soils low in humus and strongly leached, the podzolic soils developed in humid regions under the forest, are low in nitrogen. The soils of the grasslands, especially the Chernozem, are well supplied with both humus and nitrogen. Many of these can support a great many crops of grain without fertilization, and if legumes are grown and some manure is used, the problem of nitrogen deficiency never arises.

The two most important sources of this element are barnyard manure and that fixed by bacteria, especially those associated with the growth of legumes. Thus on a livestock farm in the humid regions where alfalfa or the clovers are grown and the manure is carefully conserved and used, little or no nitrogen fertilizer need be purchased, except a little for giving the corn or cotton, say, a good start in the spring. On many other farms where the soils are low in this element, like those developed under a forest vegetation and subject to leaching, a fertilizer con-

taining nitrogen must be used. Large amounts are used on these soils where truck crops, cotton, fruits, corn, and similar crops are grown without much clover or livestock.

In times past a large part of this was nitrate of soda obtained from Chile, but now sulphate of ammonia, a by-product from making coke, and other synthetic compounds are used. During the World War especially, methods were developed in Germany and elsewhere for the manufacture of nitrogen compounds by taking the nitrogen from the air, generally using electric power as the source of energy. These compounds are used especially for making explosives in war times and fertilizer in peace times.

Potassium [2] is usually contained in largest amounts in soils with much clay and those only slightly leached, although there are exceptions. Organic soils, peats and mucks, and leached sandy soils are almost always very low in this element. So are the leached soils of the tropics, even those with a great deal of clay. Other soils developed from parent materials low in potassium, or having it present in relatively insoluble forms, require additions of this element for good crops.

Manure contains much of this element. As a matter of fact, where alfalfa and similar crops that are deeply rooted and strong feeders on potassium are grown and fed to livestock, if the manure is properly conserved there is almost a complete turnover of this element and little is removed from the farm. The chief potassium fertilizers are made from salts of potassium with chlorine (KCl) or sulphate (K_2SO_4) found in underground deposits. These are now produced in the United States.

[2] In fertilizer jargon the word potash (K_2O) is commonly used instead of the word for the element potassium.

Phosphorus[8] is deficient in most soils found in humid regions and many others as well, except those developed from rocks rich in phosphate like the soils of the famous Blue Grass region of Kentucky and Tennessee formed from limestones containing large amounts of phosphorus. These soils account for the fine grass in this region, and possibly for some of the other accompanying features and traditions. Many soils, especially the eroded podzolic soils and the red soils of the tropics and semitropics, contain aluminum and iron compounds that "fix" phosphorus in forms not available to plants, including that present in the soil naturally and that added in fertilizer as well. To some extent this may be overcome by liming and the maintenance of a good supply of organic matter. In the unleached soils of semiarid regions, the excess lime that may be added in irrigation water lowers the solubility of the phosphates in the soil.

This element is the one most widely needed in United States as a fertilizer, especially on land suffering from erosion. Much of the necessary nitrogen can be obtained through the growth of legumes. Potassium and nitrogen are contained in manure, and large amounts are returned to the soil where livestock is grown. But where either grain or livestock is sold, phosphorus leaves the farm. Except for a few soils developed from rocks rich in phosphate, the normal erosion processes don't uncover new

[8] In the fertilizer trade, fertilizers containing this element are called phosphates, such as superphosphate (or acid phosphate) consisting mostly of $CaH_4(PO_4)_2$ with calcium sulphate, or double superphosphate, which is similar but lacks the calcium sulphate. There are many other forms, including the new metaphosphate developed largely by the Tennessee Valley Authority, which contains a very high percentage of phosphorus. The composition of phosphatic fertilizers is usually expressed as "phosphoric acid" (P_2O_5). Superphosphate, made by treating rock phosphate with sulphuric acid, contains about 20% (P_2O_5), double superphosphate about 45 to 48%, and metaphosphate about 66%.

minerals fast enough to keep the soil supplied since our crop plants need so much more of this element than the native vegetation does.

The supply of available phosphorus is very important not only from the point of view of crop yields but also from that of crop quality. Many minerals are essential to animals and humans, but none is more important than phosphorus. Many diseases of animals can be traced directly to deficiencies of phosphorus (and calcium) in their food, and these in turn to deficiencies in the soil that produced it. Certain diseases of humans, and possibly the susceptibility to others, are due to the same cause. This whole subject of phosphorus deficiency in respect to animal and human welfare is becoming increasingly significant.

It would be very difficult to exaggerate the vital importance of phosphatic fertilizer to sound and permanent agriculture in the United States and several other countries and to the general health of all the people. In many tropical countries with lateritic soils the matter is very serious indeed. Fortunately there are large deposits of this critical element in the United States. Whether large exports should be allowed, however, is a grave question. Improved and cheaper phosphatic fertilizer is a necessity of first importance on thousands of farms.

These elements already discussed are called the *primary* plant nutrients since they are so commonly deficient in soils generally in respect to the needs of crop rotations. There is another group, less commonly deficient, called the *secondary* elements, including sulphur, magnesium, boron, iron, copper, zinc, and manganese. Cobalt, iodine, nickel, fluorine, and no doubt others are necessary to animals, but soils are less commonly deficient in them, al-

though many important cases are known. Especially these last nine are sometimes included with a group called *trace* elements. These are also important to crop quality from the standpoint of animal and human nutrition. They are each added as fertilizers in many places, but their use is rather more specialized than the scope of our discussion.

A fertilizer containing nitrogen, phosphorus, and potassium is called a "mixed fertilizer" or a "complete fertilizer." Strictly speaking a complete fertilizer is one that contains all the compounds necessary to supplement a particular soil for a particular sequence of crops, and more and more it is bound to have this significance. Already it is recognized that magnesium, boron, sulphur, and other elements must be included in fertilizers for certain of the Yellow Podzolic soils of the southeast, and others as well. The great extent of boron deficiency on many podzolic soils has been learned only in the past 5 years.

Ordinarily the complete fertilizers are referred to as 4-8-4, 2-16-6, 8-12-8, and so on according to the percentages of total nitrogen (N) (or ammonia (NH_3) in a few instances), available phosphoric acid (P_2O_5), and water soluble potash (K_2O) they contain. The laws regulating their grading and labeling are somewhat different in the several states. Fertilizers also vary as to the other elements contained in them, their physical properties, and their acidity. One very bad feature of the emphasis upon complete fertilizers is that farmers are often persuaded to use them on soils that need only one or two elements, thus unnecessarily increasing their fertilizer bills. Perhaps there is more profit to the manufacturer in selling complete fertilizers, containing nitrogen, phosphorus, and po-

tassium, as compared to "straight goods," a fertilizer containing only one primary element. Just because some soils need all three is no reason for putting them on all soils. This is especially true with soils needing only phosphatic fertilizers. It is hoped that fertilizer salesmen and others will give more emphasis to what is needed to supplement the soil, rather than attempting a "shot-gun" dosage for a whole group of soils.

During recent years a great deal of effort has been devoted to the perfection of "quick tests" to test soils for their content of plant nutrients. Fairly accurate simple tests for acidity are available. Many are used for phosphorus and the other nutrients with good success locally. But none is available for all soils, and may never be. A test that gives reliable results on a Podzol may give very misleading results on a Chernozem or Laterite. Furthermore, the tests can be interpreted safely only by a trained technician, familiar with the nature of the soils tested, their cropping history, and the requirements of the crops to be grown. Although further progress in the development of these tests may be expected, and hoped for, in order that the proper kinds and amounts of fertilizers may be applied more accurately by the farmer, "fool proof" tests cannot be expected for a long time, if ever. The chemistry of soils and their relation to plants is not only very complicated, but very different in different soil types, especially as among those of the several great soil groups.

During the past few years the cost of the chemicals used in fertilizers has been greatly reduced. Since a large part of the present cost is made up of freight and handling charges, further lowering of prices must be expected from the use of more concentrated kinds. That is, a ton of an

8-16-8 or of a 0-48-0 contains twice as much plant nutrients as a ton of a 4-8-4 or a 0-24-0, but costs less than twice as much.

The most common fertilizer need now, on general farms in the United States, is for phosphate fertilizers; and great improvements are being made in their manufacture and application. More concentrated forms like metaphosphate are available at lower costs per ton of plant nutrients. On many farms where legumes are grown and livestock is produced, phosphate, or lime and phosphate, are the chief needs. Potash is frequently required in addition, especially on the leached sandy soils and on the mucks. Several elements are necessary on many soils, especially for special crops like vegetables, sugarcane, and potatoes, if legumes and livestock are not grown. As farmers learn to use lime and phosphate and build up their soils in nitrogen and organic matter, the other elements will become limiting factors to further progress. Increasing amounts of these will be used in the years that lie ahead. The use of all these elements is coming to be recognized as of great importance in respect to the nutritional quality of foods as well as from the standpoint of yield.

15.

CONTROL OF WATER ON THE SOIL

WATER in the soil, either too much or too little, is more commonly the limiting factor in crop production than any other factor, considering all the soils now used in the world. There may be too little water for plant growth, or too much, either all of the time or at certain periods. Some soils need drainage for good crops and others need irrigation. On many sloping soils, especially where rains come as sharp showers, excessive runoff, often accompanied by accelerated soil erosion, is a hazard when the soil is barren or planted to crops where there are wide bare spaces between the plants. Although irrigation, drainage, and erosion control often go together, sometimes they do not and first each will be considered separately.

Sometimes techniques for drainage and erosion control require special cooperative devices among farmers, but they ordinarily do not require any fundamental change in community organization on their own account. There are some exceptions of large areas of poorly drained soil requiring drainage, where extensive organizations have been made to handle rather large engineering operations and settlement. Other special districts, called soil conservation districts, have been organized to deal with problems of soil erosion, but the erosion itself is frequently a

symptom of other more fundamental causes that require the cooperative enterprise for solution. Most of the erosion control practices themselves are individual farm operations; yet the control of excessive run-off and erosion on one farm may have a great influence upon another. If such control is lacking on the soil of a high-lying farm, the excess water and erosional debris may spill over and injure the soil of a lower farm.

Although sometimes used on an individual farm basis, for the most part irrigation stands in striking contrast to the other two techniques. Where large dams and other very expensive engineering works must be constructed to irrigate soils in the desert or semidesert, an entirely new agricultural community must be organized at once where there was essentially nothing before. Whereas modern agriculture developed on the podzolic soils through long-living on the same soils, as in France, Germany, Britain, Scandinavia, and eastern United States, irrigation of the Desert soils requires the immediate organization of complete communities. Every person in such a community is very aware, or should be, of his dependence upon the others. He can't live by himself. There must be rigid protection and control. If anything happens to the water supply, to the dam or to the ditches, then orchards, crops, and animals perish at once. Many old societies dependent upon irrigation were destroyed suddenly when some invader or some revolting faction within the group destroyed the great structures upon which all depended. Suppose, for example, that an enormous blast of dynamite (or an earthquake) suddenly destroyed Boulder Dam without warning!

Drainage. This is a very old practice in modern agriculture because associated with the normal podzolic soils

of humid forested regions on which Western civilization developed, there are always spots, even some rather extensive areas, of imperfectly or poorly drained soils. Many of these soils are very productive when drained. Large areas of dark-colored soils (mostly Half-Bog and Wiesenböden) in the Saginaw valley of Michigan, in the lake plain of northern Ohio, and on the smooth plains in Indiana, Illinois, Iowa, and elsewhere, are among the most productive in the world when properly drained. Such soils developed from glacial till, loess, lake deposits, or other materials with abundant supplies of calcium and other plant nutrients have suffered little leaching and, because of the poor drainage, large amounts of organic matter have accumulated, even under a forest vegetation.

Other soils are intermediate, neither well drained nor poorly drained. Many of them have a dense claypan (the Planosols). There are many examples of these gray, nearly level or gently sloping soils in north-central United States. They are in the white patches of the so-called "black-and-white" lands of Indiana (Figure 53). They are too wet in spring time for cultivation, but in summer they may be dry and hard. By drainage, liming, fertilization with phosphate, and the growing of strong rooted legumes like alfalfa and sweet clover such soils may be greatly improved, both in structure and fertility, and made productive for other crops like corn, wheat, and sugar beets. These methods are being used on soils of this character, lying just above the dark-colored soils on the low, smooth islands in the Pontine marshes near Rome. Although imperfectly drained they can be used for pasture and uncertain crops, but their structure and fertility cannot be improved without drainage. A high water ta-

ble for only a few weeks may be sufficient to kill the roots of many plants and destroy the bacteria necessary for normal fertility.

Unglazed tile placed at some 2 to 5 feet beneath the surface are the most effective means of draining soils for crop production. Because of the uneven settling after drying, these are not so successful on deep peats, perhaps, as open ditches. Ordinarily, however, ditches are used only as a supplement to the normal drainage pattern, for straightening small streams and for carrying the large flows from the drainage tile. In open fields they are a great handicap to farming operations.

In large uniform areas the tile are laid out in a more or less regular pattern, either as a grid made up of straight lines of tile running at right angles to the main large outlet tile or in the form of a herring bone pattern from a central main tile. Where the soils to be drained lie in irregular spots and strips within naturally well drained soils, the tile must be laid as to depth, spacing, and direction according to the natural configuration of the surface and the location of any porous strata beneath. That is, if there is a spring or seepy spot in a field the tile must be so laid that they intercept the layer beneath the surface in which the water is accumulating and flowing. Frequently near the base of a gentle slope there is a series of wet places where water collects as it seeps down the slope over hard rock or a hardpan. Unless drained, this accumulated water may prevent tillage in the springtime or after moist periods and may keep the soil moist on any slope or smooth plain beneath. Tile are placed along the foot of the slope with short lateral branches to intercept the flows coming down the slope. Manuals explaining the mechanics of tile drainage and their layout are avail-

able for use by those having only a very little knowledge of engineering.

Drainage is frequently necessary in soils that are irrigated. Although the soils may have appeared to be perfectly well drained under the scanty rainfall of the natural landscape, they may have hardpans or other layers that hinder the removal of excess water during irrigation. Salts may accumulate sufficiently to injure or even kill plants. Many irrigation projects have gone to ruin on this score. After a few years of operation, seepy spots and poorly drained places have appeared. If drainage is either too difficult or too expensive, the land may need to be abandoned or refinanced to pay for the drainage system not counted on in the first place.

Along with drainage, there is also the problem of protection from overflow along streams and from the sea water near the ocean. The most widely known instances of the latter are the great dikes in Holland. These have been built to permit the pumping out of shallow sea water and the drainage of the land. Such areas are called polders. After drainage, some time is required to leach out the salty water and prepare the soil for crops. Here one can ride along the dikes and through the great canals in an ocean-going steamer during peace times and look down upon green fields and rural villages. On the east side of Lake Okeechobee in southern Florida a great earth wall has been constructed to prevent the flooding of the land during periods when strong west winds blow over the shallow lake. Numerous levees are built along many streams in the United States to prevent overflow of cropped soils. People in the United States have been too prone to build houses and other buildings in the flood plains along streams. In many other countries people

use the soils near the great rivers, like the Danube and the Volga, without building homes and villages where they are likely to be destroyed by floods. Although occasional overflows may not injure soils for certain crops, provided that the water subsides and the soil becomes well drained in time for planting, it is frequently worth the trouble to protect soils from larger overflows since many alluvial soils along streams are highly productive when drained. In such instances, it is necessary to collect the excess water from local streams in drainage ditches near the levee and pump the water up into the main stream.

FIGURE 68. View of the Badlands along the Little Missouri River. The distance from the camera to the high land directly across and to the left is about 3 miles. The natural erosion features are characteristic of the so-called "geologic erosion" in the region of Chestnut soils. As the gullies work back very slowly into the upland, vegetation covers their deposits in the lowland. (North Dakota.)

Water and erosion control. Excessive run-off over that on the natural soil usually comes about as a result of replacing the native vegetation by one less dense, on a sloping soil not highly pervious to water. Of course, only a part of the erosion that one sees has been caused by cultural changes. Especially in desert and semiarid regions many slopes are barren and have no protective covering of vegetation, or only a very meagre one, under natural conditions (Figure 68). Ordinarily it is not practicable to attempt a reduction in this natural erosion unless the land is so located as to be very valuable if made fit for agriculture or unless it presents a serious hazard to adjacent valuable land. Frequently, it is practical to control natural mountain torrents or freshets in order to protect land in the lowlands for use.

Since there are several soil characteristics that influence the ease with which water can penetrate a soil and the ease with which it can be removed, run-off and erosion are not directly related to any one of them alone. For example, if all other factors are constant, the greater the slope, the greater the run-off and erosion. Yet some soils are extremely pervious to water, like the coarse sandy soils or the porous lateritic soils of the tropics, and essentially all of the water which falls as rain enters the soil freely. Soils of this character with 70 percent[1] slope, in extreme cases, may be devoted to cultivated crops without serious injury. Other soils may be so dense in the subsoil that shortly after a rain has commenced the surface soil becomes saturated and water starts to run off, carrying considerable soil material with it unless the soil is thickly covered with plants. Some of the black soils

[1] Percent slope is equal to the rise in feet per 100 feet horizontally. Thus a 100 percent slope has 100 feet rise for a horizontal distance of 100 feet and makes an angle of 45°, like the hypotenuse of a right angle triangle.

developed from soft marl in the Alabama Black Belt or in Texas (the Rendzina soils) may suffer serious erosion on very gentle slopes of only 1½ percent. Also the longer the slope the greater the erosion, and soil on convex slopes is more liable to erosion than that on concave slopes.

Since run-off and erosion depend so much upon the vigor and density of the plants on the soil, a decrease in productivity hastens erosion. Of course, men have tried to use land for crops too steep and too erosive to cultivate under any conditions. Such erosion cannot be regarded as destructive of farm land, since it never was farm land in the sense of being adapted to crop production, although the erosional debris from such land may injure land at lower levels or fill reservoirs on streams below (Figure 69). Yet a great deal of erosion has commenced

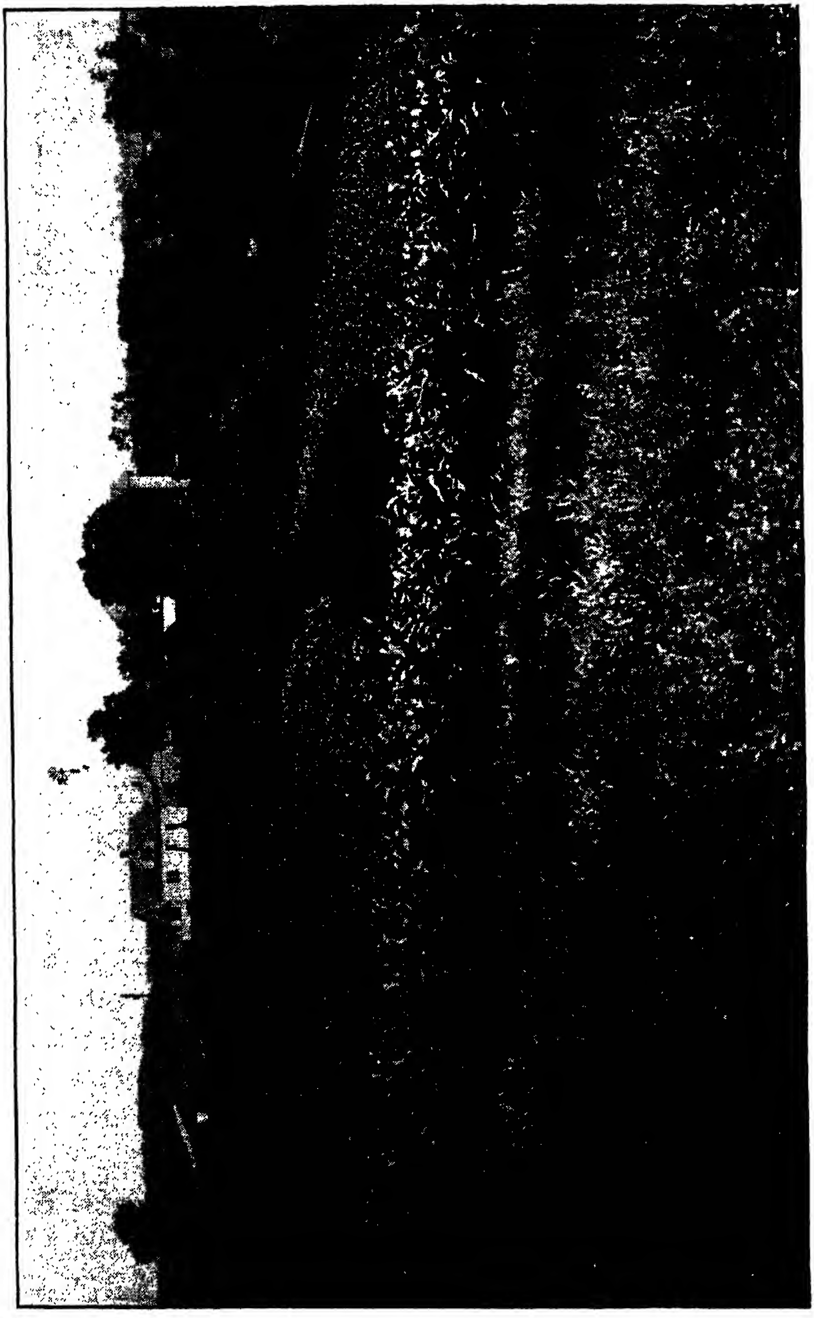
FIGURE 69. The soils on the lower slopes are protected from injury by excess run-off from the higher slopes by carefully planted wood lots. (Young sugarcane on Reddish-Brown Lateritic soil of Hawaii.)

after the land was farmed for some time; it followed a decrease in organic matter, plant nutrients, and productivity. Of course, the erosion itself would decrease productivity even further by removing the friable surface soil and exposing a lower layer with poor structure, and by reducing organic matter and plant nutrients, especially nitrogen and available phosphorus, since these are frequently more abundant in the surface horizon than in the lower horizons. Thus accelerated erosion is a symptom of declining productivity, but this initial cause may be intensified by the erosion itself. A sort of vicious circle develops.

The fundamental basis for the control of run-off and erosion must be a vigorous plant cover, which depends, in turn, upon the maintenance of soil fertility and structure. Many devices are employed to assist and supplement this fundamental practice besides liming, fertilization, and the growth of cover crops and legumes in the rotation of crops.

Terraces are old devices for water control on the land. In the United States, these are essentially low ridges, or ridges with channels on the upper side built along the slope at a slight angle to the contour.[2] (Figure 62.) On permeable soils in regions of low rainfall, and where the soils are not too sloping, level terraces built directly on the contour can be used. Level, or nearly level, terraces are used most commonly in the drier regions where water control is the primary objective. Ordinarily, however, they must be constructed so that the water may flow slowly along the upper side of the terrace and into a prepared outlet. Such structures are useful if the slope is not too

[2] A contour is an imaginary line on the land connecting all points of equal elevation.



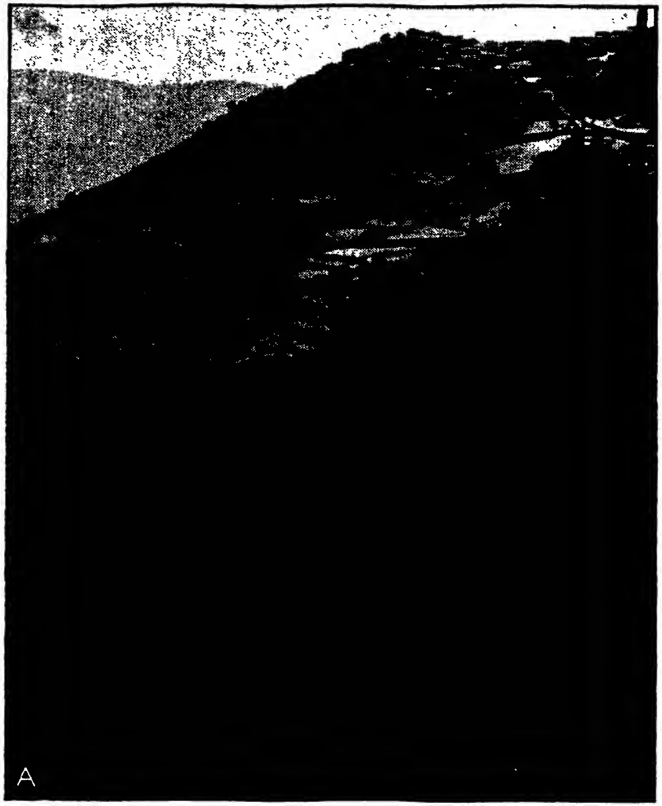
steep, if the soil is reasonably permeable, and if they are kept constantly in repair, preferably by permanent or semi-permanent grass cover (Figure 70).

On other soils terraces have even increased run-off and erosion. If the subsoil is very dense and impervious to water, the construction of the terrace may take most of the friable surface soil, requiring the making of a new surface soil from the remainder and the unproductive subsoil.[8] Again, if considerable of the B horizon is exposed, the fine clay particles picked up by the water flowing over the surface of the soil may be deposited from the more slowly moving water just back of the terrace, in the terrace channel, and partially seal the soil, making it almost impervious to water. The red soils of the southern Piedmont developed from weathered granite (Cecil soils) are of this type. Terraces are very helpful on gentle slopes, especially where there has been but little erosion, but on the more strong sloping phases of the same soil they are not so useful except when used as an aid to a permanent or nearly permanent stand of grasses and close-growing legumes, rather than for growing cultivated crops.

In many other countries today, and especially among people of ancient culture, bench terraces were used. These have essentially straight walls made of brick or stone masonry on the front side with a gently sloping or level area back to the next wall. Such terraces are fre-

[8] Example, Cuthbert soils of northeastern Mississippi and elsewhere.

FIGURE 70. Sloping, erosive soils in the Gray-Brown Podzolic region may be cultivated without injury under careful husbandry. Here sodded terraces and strip cropping are combined with the use of rotation including alfalfa. If devoted to continuous corn without terraces the soil on the slopes would be seriously eroded. (Southwestern Wisconsin.)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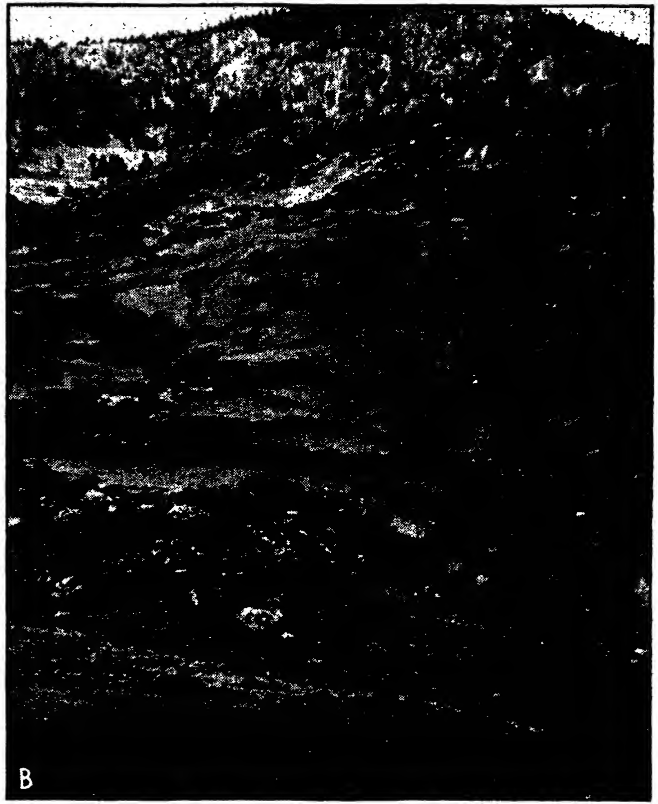
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quently built on very steep land, and the hillside resembles a gigantic stairway with treads of unequal width curving around the hill (see Figure 71). An enormous amount of labor per acre is required to build terraces of this kind and, of course, the use of heavy machinery is not practicable on them. They are used widely on the sloping types of red soils (Terra Rossa soils) developed from hard limestone around the Mediterranean Sea in Spain, southern France, Italy, and Greece, on the slopes along the Rhine, and elsewhere. Most of the flowers for the famous perfumeries near Grasse in southern France, for example, are grown on steep slopes with run-off and soil erosion controlled by elaborate and expensive bench terraces constructed from stones.

All terraces must be watched carefully. A neglected terrace is a greater erosion hazard than no terrace, since it concentrates the water through any breaks or holes, and may start active gulleying. Terraces have been built in the southern part of the United States on soil not suited to such structures because of its strong slope or impervious subsoil, or the terraces have been depended upon to control run-off and erosion with the soil devoted largely to cotton or similar cultivated crops when fertilization, liming, and rotations with legumes were also necessary. Under these conditions erosion has been stimulated and ruinous gulleys started. Also when terraces are built outlets must be carefully provided to conduct the water into the natural drainage system through well sodded

FIGURE 71. Views on Terra Rossa soils near Delphi in Greece. These soils are not especially erosive as compared to other soils on similar slopes but many areas with steep slopes are cultivated and under these circumstances erosion will be a hazard unless the land is carefully terraced. (A) A view of Terra Rossa on steep slopes, well terraced and productive. (B) A view of similar soil on which careless husbandry and excessive grazing have led to serious erosion.

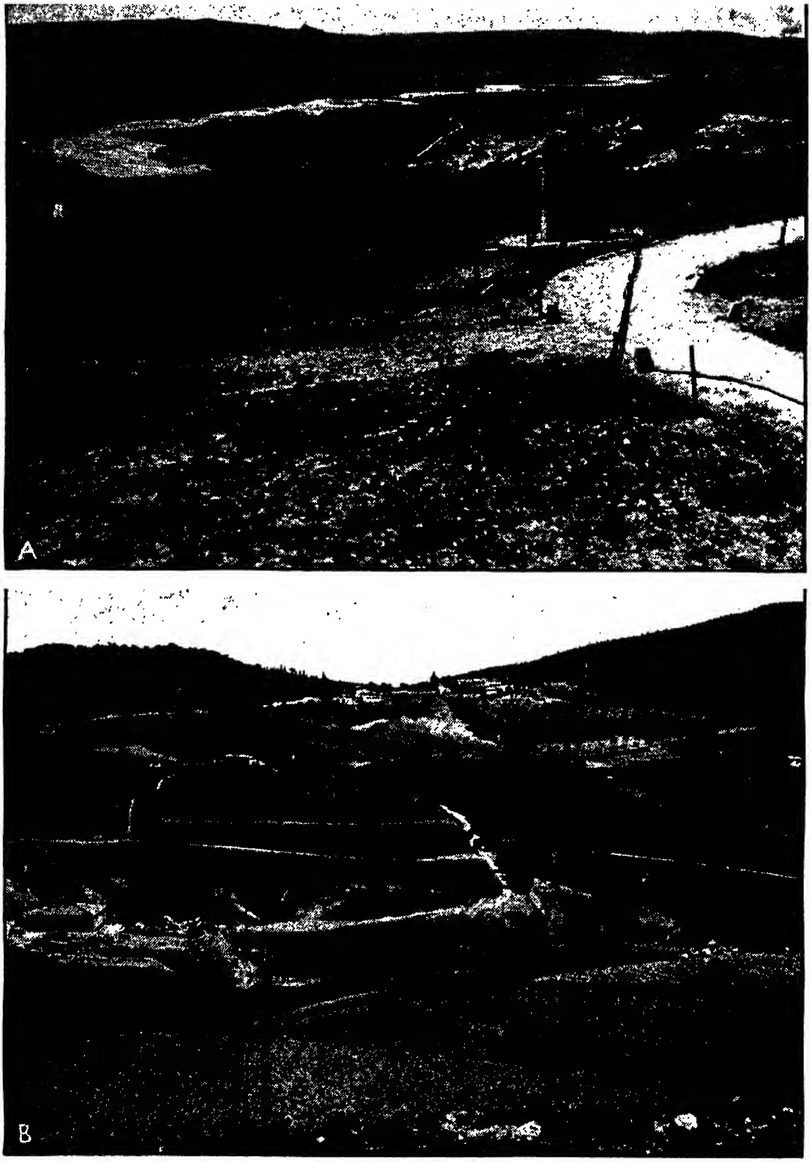


FIGURE 72. Views in the Val D'Orica near Perugia in Tuscany, Italy, on a young soil developed from soft marine clays. For centuries this soil has been neglected and has been eroding. (A) Only a small amount of work has been done here. (B) This portion has been reclaimed, planted, and good use established. Both views were taken from the same hilltop in 1938.

ditches or other protected structures. Some of the worst gulleys in the South have been started from water being concentrated at a terrace outlet or highway ditch (Figure 62).

The plowing of land on the contour, as contrasted to directly up and down the slope, helps to prevent run-off. Many farmers are now doing all their tillage and planting on the contour with frequent success. On the steeper slopes crops are frequently planted in alternating strips on the contour, or approximately so. Thus one strip may be alfalfa, the next corn, the third some small grain or alfalfa again, and so on. In this way there are no long bare slopes. The following year the order may be reversed. This practice of strip cropping may be supplemented with terraces and check dams or sod strips in the drainage ways.

Each farm presents a unique problem, and there are many devices, or rather combinations of devices to control run-off and erosion (Figure 72). One must always be reminded that the basic technique is the maintenance of soil fertility and structure and crop rotations adapted to the soil, with close-growing crops like alfalfa and the grasses on the more erosive soils as much as possible. These practices frequently mean that the farmer must have capital, security, cheap refrigeration, and reasonably steady prices. The physical problems of water and erosion control, difficult as they are, frequently are far easier than the economic and social problems involved in making conditions such that it is possible for the farmer to follow good practices. Of course, this is true of many good farm practices.

Irrigation. This practice usually requires large scale community organization for the construction of extensive

engineering works, except in those instances where farmers use supplemental irrigation from local wells or through the diversion of small streams. For successful irrigation soils must be retentive of water and allow some percolation and free drainage beneath. If the soil is too sandy and pervious, water is lost by leaking through the ditches before it can be spread over the several parts of the field. Of course, the ditches can be lined with concrete or some other material, but this is very expensive. Soils with hardpans or other impermeable layers beneath may become waterlogged when irrigated and require expensive drainage structures.

One of the most important dangers of irrigation is the concentration of soluble salts in the soil. Very few crop plants can grow with over 0.2 percent of the soil mass soluble. Of course, some particular salts are especially harmful, such as the borates and sodium carbonate. First of all, the irrigation water itself must not contain appreciable quantities of salts. Calcium carbonate and calcium sulphate are not so serious, but sodium salts and any especially toxic salts must be avoided. If there are salts in the lower part of the soil these may be brought to the surface and concentrated there by the irrigation practice itself. The water soaks down and sidewise from the irrigation channels during periods of application of water. Afterward, the water returns to the surface by direct upward capillary action, bringing the dissolved salts up to the top. If the soil is well drained and porous, and if there is plenty of irrigation water, the surface may be thoroughly flooded from time to time and the salts washed out. Sometimes artificial drainage can be supplied, but if it can't, the land may need to be abandoned.

If the salts concerned are sodium salts, like common

table salt (NaCl), the sodium may become attached to the soil colloids in place of calcium. This sodium saturated clay is very sticky and easily puddles. When dry it is hard and massive. If wetted with nearly pure water some of the sodium will react with the water to form sodium hydroxide, and this with the carbon dioxide of the air to form sodium carbonate (Na_2CO_3). Such soils are sometimes called "black alkali" soils, since they are so strongly alkaline that the organic matter is dissolved and forms a black coating around each soil grain. When this condition develops to any great extent the soil is useless for crop plants. If good drainage can be secured, the soil can be improved by treatment with calcium sulphate, or gypsum ($CaSO_4$). The calcium replaces the sodium and forms a calcium clay which is only mildly alkaline and goes readily into a crumb structure. Additions of sulphur are also helpful. Bacteria in the soil change this to sulphuric acid that immediately reacts with any calcium carbonate in the soil to form calcium sulphate. As explained before, natural soils of this general type are called Solonetz, or "black alkali."

If drainage improves naturally, the sodium-clay leaches out of the surface during the centuries with the formation of a Soloth, a soil having a profile that appears something like that of the Podzol. Many natural soils are part way between the two and are called solodized-Solonetz. They have heavy dense clay in the B horizon with well-developed columnar structure—that is, hard soil aggregates, roughly six-sided vertical blocks with rounded tops.

Salt accumulation is a special hazard when the soil to be irrigated is rolling or sloping. Water added to the soil on the higher ground or seeping out of the ditches is apt

to dissolve salts, and the salty water may seep out on the lower slopes and collect in the lower ground. Under such conditions elaborate drainage systems are essential if the ruin and abandonment of the lower-lying land is to be avoided.

Unfortunately there have been many failures of irrigation. Without government assistance in writing off some of the costs there would have been many more. Some of these failures have come quickly, others very slowly. There have also been many successes that have provided places where people have found an opportunity to develop good homes. Irrigation of a small part of an area mostly used only for grazing makes possible a much better and more stable community life for all. A large part of the failures have been due to unsuitable soil. Although a superficial examination of the surface soil may be encouraging, a soil must be examined to considerable depth by competent scientists who can predict the result of irrigation from a study of the water supply, the soil profiles, and the lay-of-the-land. In the United States there is a definitely hopeful trend toward less emotion and the use of more science in planning large scale irrigation enterprises.

Irrigation ditches on sloping land may lead to serious gulleys unless precautions are taken. The spreading of water by building broad low dams across drainageways (a kind of local irrigation) may increase the growth of grass and stabilize soil against erosion. Drainage and irrigation thus frequently go together. In Italy and elsewhere, stone or tile drains are sometimes laid down at a depth of about three feet and running at a slight angle to the contour to take off excess water. For example olives and grapes are often planted on strongly sloping, erosive

soils in Tuscany in rows across the line of slope. First, these drains are laid down at a depth of about 3 feet and the vines or trees set out in the filled trenches. The water coming down the slope finds channels through the soil and into the drains. This practice uses drainage as a substitute for terraces to control run-off and prevent erosion.

Rarely do we find a single problem of erosion control, drainage, irrigation, fertility, or soil structure. The problem is rather one of developing a complete set of practices for a farm with several soil conditions and its own special economic and social characteristics that must be somehow fitted together. In practice, the successful farmer is dealing with many problems at once, none of which can be solved by itself.

16.

WHEN DO SOILS "WEAR OUT"

SOIL is a great natural resource. Oil, coal, and iron are also natural resources. These are exhaustible; oil wells finally become dry and miners come to the end of a coal or ore deposit. Forests and soils are entirely different natural resources because they are renewable. By systematic cutting only as fast as the trees grow it is possible to cut many trees from a forest without ever coming to the end. The forester calls this "management on a sustained yield basis." Instead of building an enormous saw-mill and engaging large groups of engineers, foresters, and other workmen for a short period during which all the trees are cut and at the end of which there is nothing left—instead of this rapid cutting a smaller mill is built and a smaller group of men are given permanent employment, cutting each year as much as the whole forest can produce in one year. If it requires 70 years to produce a mature tree, let us say, then about one-seventieth of the forest growth is cut each year, with care to protect the young trees or replant seedlings if necessary.

A very similar principle applies to soils. One can use them without regard to the future—with only the thought of immediate crops that may be sold. During boom periods of abnormally high prices—one may say ruinously high prices—many are tempted to use soils for wheat or

cotton or beans or corn, year after year, whether the productivity of the soil is ruined after a short period or not. If a little longer view is taken, a system of crop rotations and soil management can be used that will maintain,[1] or perhaps increase, the productivity of the soil. Thus by resisting the temptation to get the very most money this year and next, the farmer can have a great deal more from his soil over the 10- or 20-year period, with the soil in a good state of productivity at the end of each year. Management for immediate gain is thus contrasted to management for secure production.

This thought leads to the meaning of conservation as applied to such natural resources as soils and forests. It certainly doesn't mean simply saving, or denial of use. People live by the soil and make their homes on it. Rather conservation implies use—full use—on a "sustained yield basis" or for "secure production." Soil conservation is thus less an end to be sought in itself than a handmaiden, or result, of soil management for secure production.

We must always remind ourselves that production from soil is the result of both soil and husbandry or management. At least some work must be done. This work may be very little, perhaps little more than building a corral and cleaning out water holes for range cattle. Or the practices may be much more complex and include tillage, green manuring, drainage, liming, and the use of fertilizers, beside many more, all on one field.

If we say that some soil is productive for corn or for sugarcane we mean that relatively high yields of the par-

[1] There are a few exceptions to this statement. For example, certain very productive Prairie soils, like some of those in Iowa, may have a higher productivity during the first few years of cultivation than it would be practicable to try to maintain.

ticular crop can be obtained for the amount of work done, or for the cost of producing the crop. Good crops of grain may be obtained from some soils, such as the good Chernozems, Prairie soils, or Brown Forest soils by simply clearing away the native vegetation, plowing, and seeding. Others, like the Yellow Podzolic and Brown Podzolic, may produce little under such conditions. Yet they may respond well to fertilization, liming, and a rotation with legumes. Many of the sandy podzolic soils developed under forest vegetation in a warm humid climate contain small amounts of plant nutrients and organic matter. They are naturally infertile. But because of the favorable climate and good soil structure they may respond well to careful management. They are productive.

Thus soil productivity is a matter of response to management. It is measured in yields (and quality) only under a specified management. Without irrigation and heavy fertilization many of the Reddish-Brown Lateritic soils of Hawaii would produce little sugarcane, but these soils are very responsive, and with careful tillage, well-bred varieties of cane, extensive fertilization, and so on they may produce as high as 0.8 ton of sugar per acre per month on the average, with yields for a single crop (requiring a little less than 2 years for growth) as high as 180 tons of cane, or over 18 tons of sugar per acre.

Other soils may not respond to management. They may even be fertile, that is, contain the necessary nutrients

FIGURE 73. Accelerated erosion of sloping lands due to improper use, in this instance overgrazing and lack of the necessary fertilizer. Near the center of the opposite hill note the line fence separating the well used land on the left from the poorly used land on the right. (Courtesy of the Tennessee Valley Authority.)

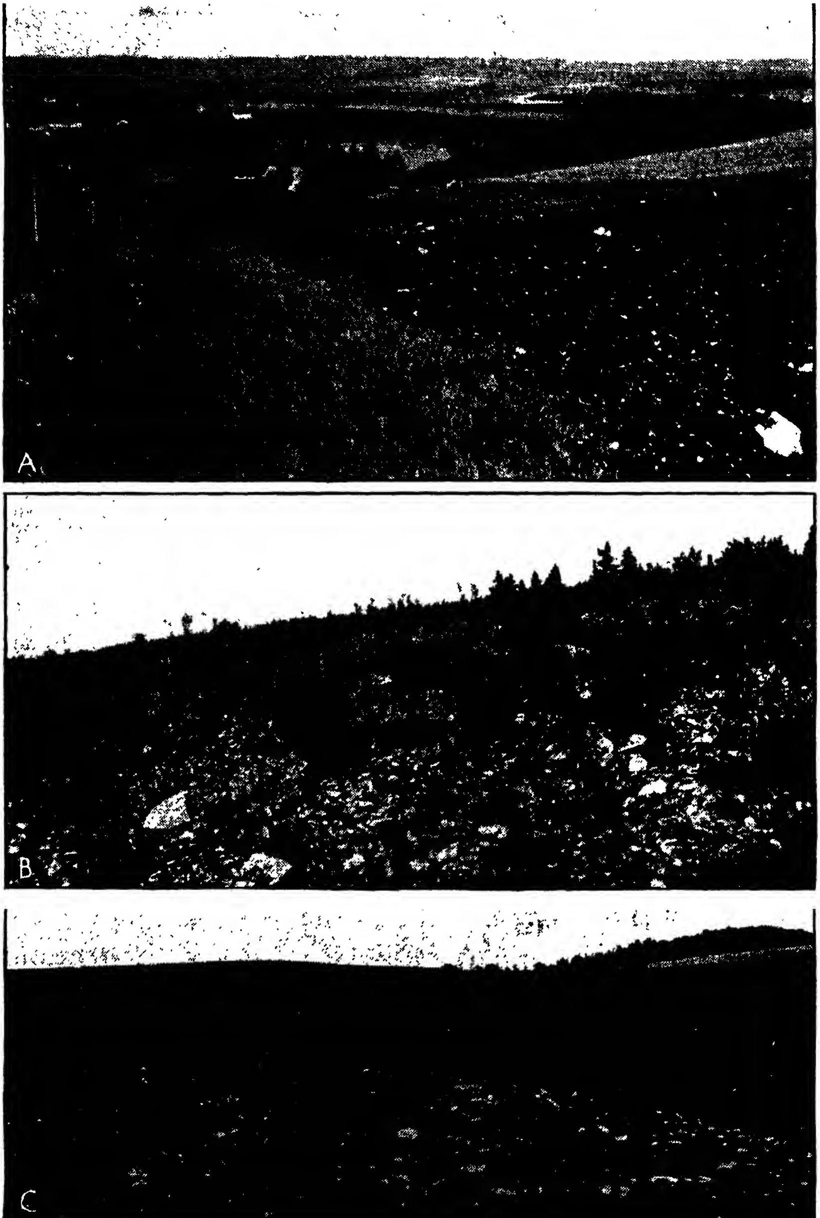
for some crop in forms available to the plants, but because of poor structure roots cannot grow normally, or because of steep slopes the soil is subject to erosion or machinery cannot be used. In parts of the humid region it is common to find side by side two soils of about the same low natural fertility for plants with about the same low productivity under a system of management that includes only plowing, harrowing, and seeding. One may be very responsive and yields can be pushed to a high level quite easily; whereas it may be impracticable to attempt to increase yields on the other (Figure 73). When comparing yields on different soils this point must always be borne in mind. One must expect a great range in yields on different fields having exactly the same soil type, if the soil is very responsive, because of the differences in husbandry among farmers. Some people have misinterpreted such variations in yield as an indication that the soil maps were incorrect when, on the contrary, they were a normal thing to expect on soils highly responsive to fertilization. Where farmers followed the same management, yields were the same.

A change then in yields up or down may be a result of either soil or husbandry, or both. On many soils simple tillage and seeding may lead to good crops for a few years and they may slowly, or even rapidly, decline if this simple practice does not maintain fertility and structure. It might be said that the soil begins to "wear out." The time involved and the management practices required to maintain yields will be different on almost every soil type. Continuous use for cultivated crops, without the use of manure or fertilizers or the growing of legumes, will cause a rapid decline in yields on the leached, light-colored podzolic soils of humid regions. On the nearly

level Prairie soils continuous cropping to corn leads to a decline in yields, but a very slow decline. As we have already seen, this decline in productivity may lead to accelerated erosion on some soils, then a still further decline, and perhaps finally abandonment and serious sheet wash or gullying (Figure 74). Many soils are not subject to erosion, but may become so infertile and acid that crops cannot be grown practically.

Thus, many of the so-called "worn out soils of the East" never were much more productive. Crops were grown for some years and the soil was abandoned in a state little worse than its natural condition. The gray nearly level soils along some of the eastern seaboard are good examples. Again soils of this character may be built up to a fairly high state of productivity and cultivated with good yields by one or two generations of farmers, only to be allowed to decline by the next from lack of care. There were many plantations with fair to good yields in Tidewater Virginia in years gone by, where there are pine trees now. One may walk into the woods and find the ridges of old corn rows. This soil is not much, if any, less productive today than it was naturally, but the competition of more fertile land in the west and other reasons persuaded people that it was not worth the trouble to keep up a high state of productivity. Some probably hadn't learned how to do it, or didn't look ahead beyond the next crop anyway. There are soils in England that during the centuries have been built up to a high state of productivity, allowed to decline to a state of waste-land, then built up again and allowed to decline, again built up, and again allowed to decline. Without doubt they began another upward swing in 1939.

Usually, but not always, soil is abandoned in a poorer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state than its natural condition. Although some soils are so infertile for crops under natural conditions that they must be carefully farmed for several years before satisfactory yields can be obtained, others are naturally highly fertile, have good structure, and return maximum yields at once. When the dark-colored soils of the Middle West are abandoned because of declining yields and erosion, it means that a great injury to the soil has occurred which may require many years to repair. This is especially true where deep gullies have been formed or hard rock has been exposed.

No accurate studies have ever been published on the rate of soil formation. All sorts of wild guesses have been made. Many of these are expressed in "years to produce an inch of surface soil." Soils don't form from the top down as such a statement implies, unless we start with bare rock. Rather all the horizons begin to develop simultaneously. The time required to produce parent material for soil varies between extremely wide limits. Fresh deposits of alluvium may be laid down by a great river in one evening, and there are old mountains with surfaces that have been bare for millions of years. Possibly about 500 years is required to produce a normal Chernozem from a partially weathered rock, like glacial

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FIGURE 74. Views in northern Maine on Podzol developed from calcareous (limy glacial till). (A) A general view showing the gently rolling landscape with a slope in the foreground that has lost much of the original surface soil through accelerated soil erosion, caused by too much cultivation for such a sloping soil. The plowed soil shows the accumulation of glacial stones. The present surface soil has now become too alkaline, through the incorporation of the underlying fresh glacial till, for the best growth of potatoes, the principal crop of the region. (B) A severely eroded slope, no longer productive of farm crops because of poor husbandry. (C) A stony alluvial fan consisting of material washed from eroding higher slopes and deposited over soil formerly productive. It may be noted from this picture how use of the soil by one farmer may influence the soil on another farm.

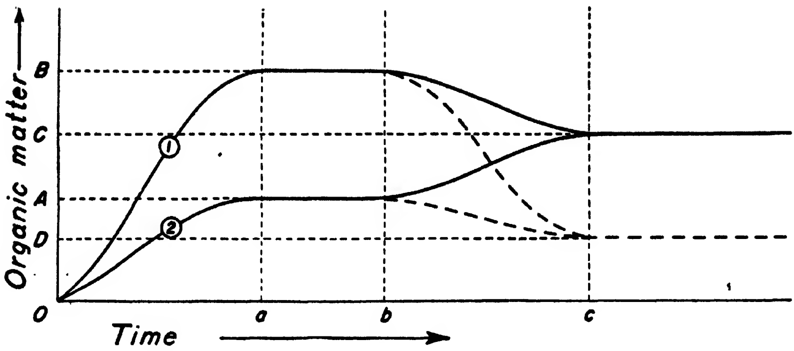

FIGURE 75. A simplified diagram illustrating how some soil characteristic may change in response to a change in the environment. In this instance, changes in the content of organic matter are considered in relation to changes in vegetation. Let us suppose that two soils develop from some parent material, say glacial till, alluvium, or loess, on smooth relief in a temperate humid climate like that of southern Wisconsin, (1) under tall grasses, and (2) under trees. As soon as the plants begin to grow and produce organic matter, soil formation begins and organic matter starts to accumulate in the soils. As accumulation increases, decomposition increases, until finally points are reached where the one just balances the other. The soils are then in equilibrium with their respective environments, the one under grasses at a relatively high content of organic matter, *aB* on the upper curve, and the one under trees at a lower content, say *aA*. The characteristics of both soils will remain constant indefinitely as long as there is no change in the environment.

Now let us suppose that at some later time, represented by *b*, the soils are cultivated and devoted to a series of crops including some intertilled crops, like corn, and some close-growing grains, oats and wheat, and legumes like alfalfa or clover. Both soils will move toward a new equilibrium, below *B* and above *A*, say at *C*. If, on the other hand, the soils were devoted almost wholly to intertilled, harvested crops, like corn, the new equilibrium might be reached at some point *cD* even below *A*.

till, under its normal vegetation, perhaps somewhat more or less. It may take even longer for the podzolic soils to develop. We know that when a soil has become mature—come into equilibrium with its environment—it doesn't change. That is, suppose it required 500 or 1000 years to produce a soil—it probably could remain there for 10,000 or 100,000 years more with little or no change, if the environment didn't change.

This principle can be shown best, perhaps, by considering one characteristic of some ideal soil—content of humus in the A horizon (see Figure 75). We might start with some raw parent material, such as loess or glacial till, near the boundary between the grassland and the forests—between the Prairie soils and the Gray-Brown Podzolic soils—near southern Wisconsin, say. At the start there would be no organic matter, of course; but as soon as plants began to grow, humus would tend to accumulate, at first more rapidly than it decomposed. Finally a point would be reached at which decomposition would just balance additions by the plants. This would be the point in time when the soil had reached an equilibrium with its environment, and from then on, as long as the environment didn't change, the percent of humus would remain constant. The amount would be considerably higher in the Prairie soil developed under grasses than in the Gray-Brown Podzolic soil developed under forests.

Now suppose the environment were altered by man, changing the vegetation to a rotation of crops consisting of corn, followed by oats, followed in turn by 2 years of alfalfa. This would likely lower the amount in the Prairie soil but raise that in the Gray-Brown Podzolic soil. After sufficient time, how long is not known, both soils would readjust themselves to the new equilibrium,

probably at very near the same amount. That is, a decline in humus content must be expected if the new environment furnishes less organic matter to the soil than the old. But because a soil lost 30 percent of humus during 30 years of cropping does not mean that it will keep on losing it at that rate. Ultimately a new equilibrium will be reached. Continuous cropping to corn would even reduce the humus in the Gray-Brown Podzolic soil, and greatly reduce that of the Prairie soil. If the soils were on strong slopes accelerated erosion might hasten the reduction. Severe erosion may remove the soil completely, and only after stabilization and the coming of a new vegetation can soil start to form once again.

There are then no exact data by which it is possible to know how long it takes for soil to form, or how long be-

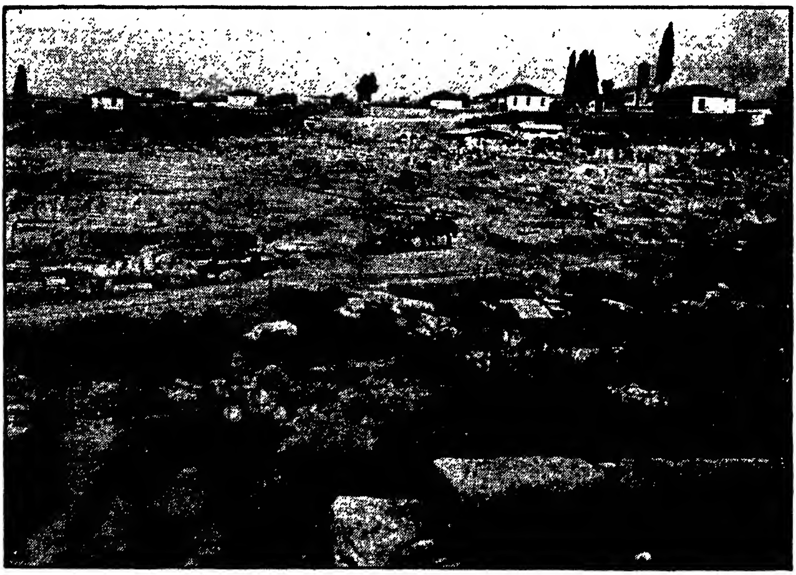

FIGURE 76. Excavating the ruins of old Corinth in Greece, once covered by erosional debris (geological erosion) brought down from high mountains at the right (not to be seen in the picture).

fore natural soil will develop on eroded, abandoned land. We don't even know whether it is a matter of a few hundred years or one of a few thousand, but it is probably more nearly the former, at least in most instances. Many eroded soils can be restored in a few years. Careful studies of the profiles of present soils and those of old buried soils in relation to excavations where there are remains of previous cultures would, perhaps, be very useful (Figures 76 and 77). These results might make it possible for soil scientists to reconstruct the history of the soils in relationship to the history of civilizations. Then knowing the general trends of soil formation in an area it would be possible to predict more accurately the probable future course of the soils under different kinds of management.

Soils in Europe have been farmed for centuries without injury; in fact yields have been rising steadily for over 150 years. There are smooth soils in Puerto Rico that have been producing sugar almost continuously for over 300 years—since before the Pilgrims landed—and yields have more or less steadily risen. Agriculture developed to a high level in Roman times, then started to decline quite some time before the Age of Augustus, but probably the soils of Italy were producing more in 1939 than ever before.

Many soils in the Podzol regions, developed in a cool moist climate under spruces or pines, have been cleared, treated with lime, and used for hay and pasture a large part of the time. If legumes are grown and enough lime and phosphate added to supply their needs, these soils may gradually develop the characteristics of a Prairie soil with a great increase in productivity for crop plants. This has happened on many farms in northern Europe.

Should the land be abandoned to the forest it would soon return to its former state. Thus, as the farmer changes the environment, the productivity of the soil for crop plants changes, either up or down.

Severe fires, extreme depletion of plant nutrients, injury to soil structure, or erosion make it impossible sometimes for the original vegetation to return at once after land is "worn out" and abandoned. On podzolic soils frequently pine or scrubby oaks follow abandonment, and not until 30 or 40 years do young hardwoods, like those in the original forest, find it possible to grow again. Once the native short grasses of the Brown and Chestnut

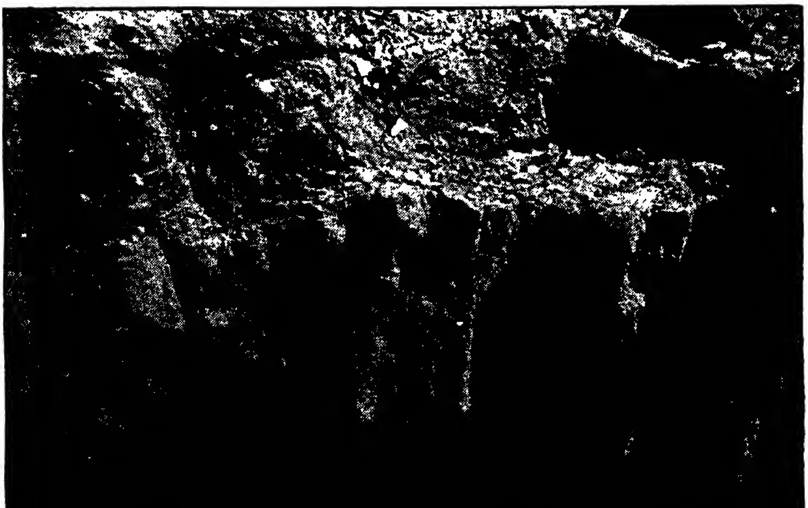

FIGURE 77. A mature soil is shown here developed from fine wind-blown material deposited above an old hearth, which was used many centuries ago by prehistoric man. Studies of soil morphology and archaeology should go hand in hand. (Western Nebraska.)

soils of the Great Plains have been destroyed by cultivation, many years of weeds and other grasses precede the reestablishment of the native grama and buffalo grasses.

Soils then do not "wear out" in the sense that an automobile wears out. They may become poorer for crop plants, for forests, or for range plants as a result of improper management—that is, a management that does not maintain those characteristics that are responsible for productivity. If such management is followed by extreme erosion, many years—even centuries perhaps in extreme instances—may be required to restore them to their natural state. But usually they can be brought back to a good state whenever men know what to do and want to do it. More often, something happens to the people on the land first. Sudden drops in prices, wars, disease, ruinous taxes, loss of security—such calamities may befall the farmers on the land; and they may be forced to farm the soil on a year to year basis in a desperate attempt to make ends meet. It has been said that, "An exploited people pass their suffering to the land."

Sometimes people move into a new area, on to a soil that is new to them, and try to use the methods they found successful on another soil. This has happened dramatically in the drier regions of the American Great Plains. Before they learn what should be done, the soil may have lost some of its productive capacity, which makes the task of readjustment even more difficult. It is on the soils least like those in western Europe, from whence the early farmers came to America, that it has been most difficult to discover, by trial and error, the methods that should be used. Some people hope that the development of the new science—soil science—may make it possible to hasten the progress toward an adjust-

ment, and lessen the failures. Perhaps this may be possible, but even accurate knowledge of what to do can help only to the extent that farmers can and do follow the practices necessary for secure production. The failure of soil is largely a failure of men—and with this problem soil science is not equipped to deal by itself.

17.

PLANNING THE USE OF THE SOIL

PLANNING is a rather simple English word that has come recently to mean all sorts of things to different people. Here let us take only the old meaning of trying to prepare for the future, or of prearranging a course of action for the future, through the use of such experience and knowledge as we have. These activities are subject to frequent revision as knowledge grows and experience broadens. Sensible people are almost constantly engaged in planning. All farmers are planners—some good, some not so good, perhaps. But when the first nomad or hunter settled down at some place and began to till the soil, however crudely, and plant seeds, he became a farmer. When he ceased to be a sort of thief and began to cooperate with nature, began to sow instead of steal, man became a homemaker, a planner and conservationist. It has turned out sometimes that he didn't see far enough ahead to plan for secure production, or was somehow prevented from doing what was necessary.

There is a problem of maladjustment between the soil and people living on it in the United States. Its symptoms are rural poverty, poor health, and unhappiness among many of the farm people and depleted productivity and, in some places, erosion of the soil. In 1938 some estimates were made by the Department of Agri-

culture of the extent of this maladjustment.[1] It was found that on about 76 million acres (18 percent of the crop land) being farmed there was no known agricultural practice that would return a satisfactory income for the labor required and maintain soil productivity. This includes soil types too stony, too sandy, too steep, too erosive, or too droughty to return an income with the average prices for crops that farmers had been getting for the previous fifteen years. Much of this soil is now suffering from erosion or blowing. Of course, this is not good farm land, at least not now, but the erosion injures it for other uses and the debris may cover other good soils or fill streams and reservoirs. New agricultural practices are being developed from time to time and perhaps practices will be discovered that can be applied successfully to a part of this 76 million acres.

According to the same study, there are another 178 million acres that are being used for crops by practices that either do not return a satisfactory labor income with prices that farmers have received during the past fifteen years, or deplete further the productivity of the soil, or both. But with these acres, practices to achieve these results are not only known, but are being used by many farmers.

The remainder of the crop land, or 161 million acres (according to the Census of 1935), can be farmed by the practices now being used without danger of erosion, although a part of it may be subject to injury of structure. Interestingly, the same study showed that there were 51 million acres, not now used, that could be used and added to this last category, to the 161 million acres. If the best

[1] "Soils and Men," Yearbook of Agriculture for 1938, pages 56 and 95.

practice were followed, over 100 million acres could be added to our total crop land.

To summarize, with the best farming practices, now known to some farmers, and with price levels for farm products like those which farmers have received since 1920, the total crop land in United States could be increased easily from 415 million to 448 million acres and productivity at least maintained, even increased in many instances. This would also count out of use for crops the first 76 million acres of poor soil now being used. Of course, this would mean a great increase in total agricultural production because these shifts from one group of soils to another, and the use of practices leading to secure production, would also have the effect of increasing yields. Such an increase might make the matter of prices acute, since there is a limit to the farm products farmers can sell at home and abroad. The problem is by no means one for the soil scientist alone.

Since these estimates were made, no doubt improvements in the use of the soil have been made through the general awakening of public interest and the efforts of such great public programs as those of the U.S. Department of Agriculture, the Land Grant Colleges, and the Tennessee Valley Authority. Probably the first two figures, especially the second—the 178 million—have been much reduced and the 161 million increased. Above all, the problem must be seen primarily as a human one of the people on the land. There is no danger of the United States running out of land or of a threat to the food supply from soil depletion alone. The real questions are: First, what of the people, and their children, on the 76 million acres not suitable for cultivation? Second, how

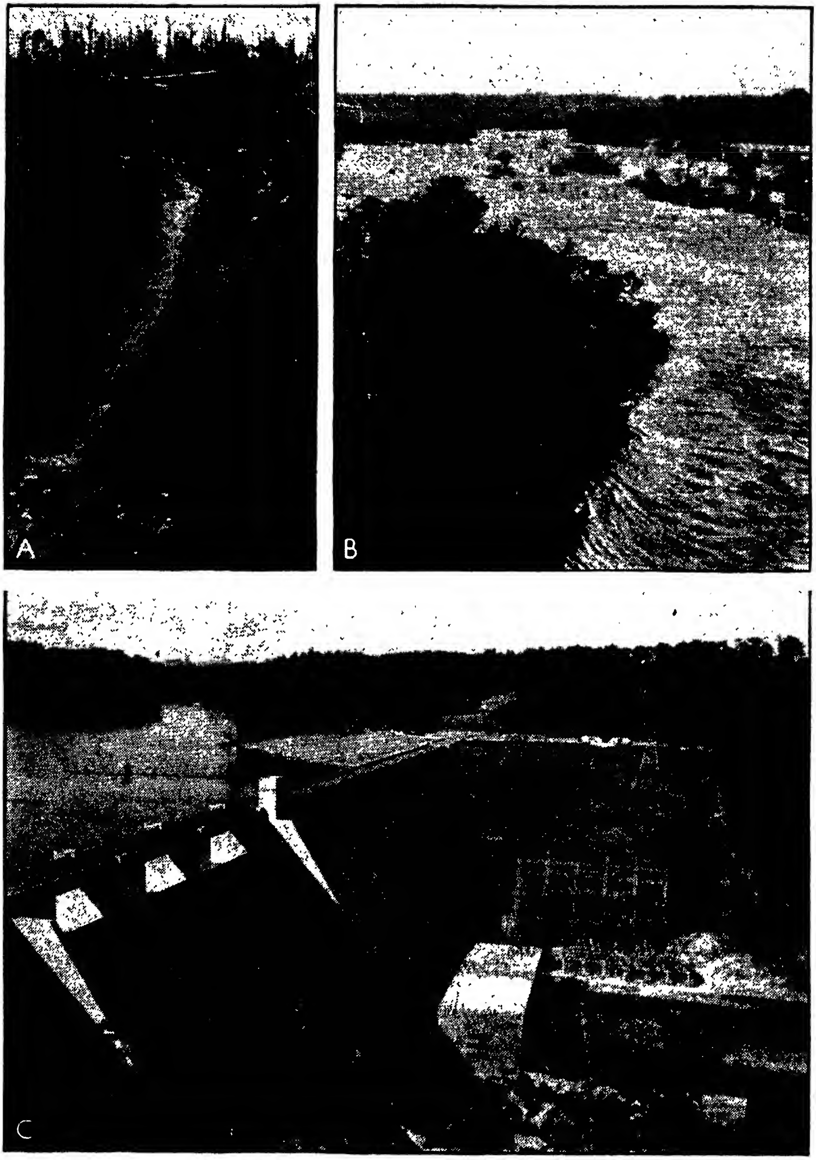

Figure 78. The high rainfall, including sharp showers, of southeastern United States leads to frequent floods of the small streams. (A) Little streamlets begin to flow almost at once on crop land with the start of a shower. (B) Floods become intensified with poor husbandry that permits rapid run-off and excessive erosion. (C) Dams on these

can farmers on the 178 million acres be persuaded to follow good practices and how can it be made possible for them to do so? To these might be added a third: What of the thousands and thousands of landless people, agricultural people, who want a secure home on the soil?

These problems are not new in the world, not by any means, but they have come forward very forcibly to us in America because we have reached the end of the great expansion to new land. Ever since the first colonists came to America there had been new places for the unhappy, the adventurous, the misfits, and the discontented to go. First there was the Atlantic seaboard itself, then the Piedmont, the limestone valleys, the great Mississippi valley, and so on to the West. Now we must live where we are. During the 19th century many problems did not absolutely need to be faced. The new lands in America offered a great safety valve, a great refuge, a great "relief program," for the discontented, not only in America itself but also in Europe. There arose, therefore, the vague notion that anything like national planning was unnecessary—somehow people would "muddle through"; they had for a great many years. But the ever available great area of new soil that made the muddling through possible is no more. The muddling through characteristic of English and American peoples thus grew out of the free land situation. When free land was no more, a great conflict arose between the old concepts and the new requirements for planning.

Older civilizations faced with such problems followed

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streams prevent floods on the large streams and the power may be harnessed to allow the development of refrigeration and other facilities essential to better husbandry on the land. (A. and B. North Carolina.) (C. Tennessee.)

the trial-and-error method, with many, many individual disasters and frequently general collapse from the failure of military protection or from internal social rot. But during the past two centuries people have forged a new tool—science. Many people think that the great resources of science can be used to avoid such disastrous failures. Instead of the fumbling, unconscious, trial-and-error way of arriving at an adjustment between the soil and the people, a conscious attempt can be made to approach this adjustment, to guide and harmonize natural and cultural processes. Planning means just that.

The central problem of planning is by whose consciousness shall this conscious attempt be made? Already planning has been discredited somewhat because it has been advocated by certain people with selfish motives, or by sincere but unbalanced people, driven by some "single purpose." The life of people is very complex and there are many, many aspects to be considered. For example, the net result of planning for secure production from the soil might be unhappiness, or even national disaster, if, in doing that, such values as freedom, democracy, education, and health were overlooked. Planning in a democracy like that of the United States seems, on the surface, to be more difficult than in a dictatorship, because so long as people are free they will insist upon all these human values being considered. In a democracy the planning must come from discussion and agreement among the operators, or the citizens, the experts, and the administrators. Any other course calls for a sacrifice of either planning or democracy, that is planning in a positive sense. Farmers cannot establish good practices by deciding only what not to do. New methods must be devised where the old have been found to be bad.

The success of planning depends not only upon the accuracy with which one can predict the results of individual actions, such as the influence of a certain fertilizer on yields, the growth of apple trees on a particular soil type, or the effect of irrigating some soil, but also upon the completeness with which all factors have been taken into account. A farmer or agricultural scientist may become so specialized that, although he foresees certain things very well, he may overlook other critical factors that finally ruin his plans. When proposals are made that are greatly different from current practices one must always be careful that some factor hasn't been overlooked. New practices are frequently good and successful, but especially careful research is necessary to assure their success where there is little or no guiding experience.

There are two primary aspects of planning the use of the soil from the point of view of the farmer: (1) those things that he does as an individual on the soil he tills, and (2) those things that are done on a community, regional, state, national, or international basis, by many individuals working together in some sort of social institutions. The first is concerned with things within the boundaries of the farm and the second with things outside these boundaries.

In cooperative affairs he may have a part, but not the controlling part as an individual. He must cooperate not only with his neighbor farmers, but also with other people who work in cities, in the mines, and on the sea. Some of these measures taken by the social group are legal or institutional, such as arrangements for tenure and credit; whereas others result in physical structures such as railroads, hydro-electric power plants, and fertilizer factories. It is not always easy to separate one from the other

sharply, or to distinguish between private group action, corporations chartered and regulated by the government, and strictly governmental enterprises.

These principles may be seen most easily, perhaps, by taking some examples. First, some of the more important considerations outside of the individual farm boundaries are mentioned:

1. Military protection is essential to a stable agriculture, especially one depending upon irrigation dams, railroads, and control over its own political affairs. The destruction of certain key portions of the agricultural community has sent many an ancient group on the path to ruin.

2. Security of tenure in the use of the soil is essential to farming on a secure basis. In the United States, perhaps fee simple ownership has been given too much emphasis. Tenancy is not necessarily bad—rather those systems of tenancy are evil that give the farmers no assurance that they will obtain any compensation for good practices, either as increased yields or in other ways.

A tenant with a year to year lease, that may be terminated at any time through no fault of his, and with no provisions for compensation for long time improvements he may make, has no urge to improve the soil, even though he knows what to do and believes that it should be done.

Some system of renting farm land is not only necessary but highly desirable. Many young men could not become farmers unless they could first rent land and get a start. If successful, they can purchase land of their own later; or as they grow in experience, they can rent larger tracts and undertake greater responsibilities. Much of the present effort directed against tenancy in general

might better be directed against the bad systems and toward good systems.

One result of farm ownership has been a great transfer of money from the country to the city. Many farmers had large families. Perhaps one son remained on the farm and the others moved to the city. When the father died, the son bought the farm, except for his share, from the other heirs. Many farms have had to pay for themselves over and over again with most of the money going to the city, rather than remaining in the agricultural community for its development.

3. Prices, tariffs, and bounties—all kinds of devices for influencing the income to farmers, or the costs of the things they buy, are very important to the use of the soil. On most soils satisfactory yields on a secure basis depend partly on well-planned crop rotations. Sudden changes in prices disturb these plans as farmers make shifts to take advantage of high prices or to avoid the bad effects of low prices. General trends downward may force the farmer to shift more to cash crops in a desperate attempt to make ends meet accompanied by an inevitable decline in soil productivity.

Tariffs may raise the price of goods the farmer must buy while he sells on a world market. This situation has been very serious to farmers generally in the United States. At the same time a tariff on sugar has favored the growth of sugar beets on soils that can produce them. Yet without this subsidy in the form of tariff, they could not be expected to compete with the soils of the tropics adapted to sugarcane. Seemingly prosperous areas could then lose their prosperity by some caprice of politics that removed the subsidy, since they are not founded upon really efficient production.

4. Credit facilities are very important to the use of the soil. Without credit many farmers cannot make the shift from cash crops to diversified farming with livestock, even though they would make more money and improve the soil over the long run. It takes money to build up herds and flocks; there is a delayed income. If credit is too hard to obtain, farmers are forced to follow "hand-to-mouth" methods; if too easy, they may be persuaded to purchase machinery, buildings, and automobiles beyond the capacity of the soil to support.

5. Transportation facilities must be available for anything more than the most primitive agriculture. Early agriculture was confined to soils near the sea and navigable lakes and streams. Not until the development of railroads could the great area of Chernozem and Chestnut soils be used for crops. Even today in the United States, corn may sell at 80 cents per bushel in one place and at over 2 dollars 400 miles away. Inequalities in freight rates and the development of cheaper river routes are thus matters of importance to many farmers.

6. Taxation is of more importance to the use of the soil than many folks realize. Associated with the problem of taxation are problems of public services for health and education in rural communities. Most agricultural communities are taxed, for example, to educate people who later go to live in the city. Very few cities have had the expense of educating more than one-half of their own people. With such a complex modern society, agricultural communities must resort to property taxes on the land because other property, such as the factory making the machinery sold in the community, cannot be reached. Nor can they reach the incomes of those who make profits from trade with the community.

Further, the problem of the assessment of rural lands for taxes in accordance with their producing power is acute in many parts of the country. Generally, the farms with the less productive soils are overassessed and overtaxed. Recently several counties in North Dakota have reassessed their rural land from carefully prepared soil maps in accordance with the ability of the soil to produce. Elsewhere some inequalities are being adjusted, but in many places the taxes are more than the soil can support. Much land has gone back to the state because the taxes could not be paid.

7. The construction and maintenance of dams and other large structural works frequently have an enormous obvious importance to many individual farmers (Figure 78). Many of these require not only more than the farmer can do alone, but even more than the local community can do as, for example, Boulder Dam. Ordinarily drainage structures are not so elaborate, but those for the development of electric power, for flood control, and for irrigation are frequently of great cost and require great skill to build and to maintain. The use of many soils and the welfare of thousands of farm families already depend upon their success.

8. The distribution of electric power is rapidly becoming of fundamental importance to planning the use of the soil. In many ways it permits diversity of the farming enterprise—increases the possibilities of use of the soil. Perhaps the most important of these is refrigeration, so necessary for the production of livestock products in the warmer sections of the country, but there are several other important uses of electricity. As the cost of electric energy comes down, it will become increasingly significant to the work and living of the farm. Perhaps it

is the most important physical technique made available to the farmer in modern times.

9. The manufacture of modern fertilizers and farm machinery, of course, cannot be done on the farm. Although these are produced by corporations, their activities are somewhat regulated by laws.

10. Research and the extension of the results of research are important activities that very few farmers can do for themselves. Many years ago it was recognized by people generally that research in agricultural science would need to be conducted by associations of farmers or the government because of the complexity and technicalities of the work and because the farmers were scattered all over the country on hundreds—thousands—of different soil types. State agricultural experiment stations have been established for many years in each of the states, partly with federal funds; and the conduct of research, in cooperation with the state institutions, is still one of the chief functions of the United States Department of Agriculture. If one goes over almost any well-managed and successful farm today he can trace the varieties of plants grown, the soil treatments, the breeds of livestock, the methods of accounting, and so on, to work done by the scientists and economists in these institutions. Many of the methods used and plants and animals grown today are the results of very technical studies carried on for a long time, here and in foreign countries. Individual farmers could not have been able to conduct these studies, which are comparable to those carried on by all forward-looking large industrial corporations.

These results must be classified as they apply to different soil conditions, and one of the chief functions of those engaged in soil research is to study the different soils, ar-

range them into a system of classification, and show their distribution upon maps—detailed maps that will show the fundamental soil conditions on individual fields and farms. Such soil maps are not only fundamental to the application of the results of soil research to individual farms, but also to recommendations of kinds of crops and farm management practices in general. This work was begun many years ago also—just before this century started—at first somewhat crudely, but with increasing accuracy and completeness. (See Appendix I.)

The teaching in the agricultural colleges makes the results of the research in agricultural science available to students, many of whom are prospective farmers. Through the Extension Service, organized in each state in cooperation with the United States Department of Agriculture, the results are made available to the farmers by the county agents and other specialists. Special bulletins are prepared for use by farmers setting forth the results of recent experiments. The farmers have many, many problems today, but the great advances in agricultural science in the United States and a few other countries have made possible a standard of living on farms almost unheard of in most other countries or at other times. But a great deal needs to be done in making the information available and useful, especially to the less fortunate farmers and to groups of farmers with community problems that must be solved on a community basis.

11. Rural zoning ordinances, associations or districts for planning measures for soil erosion control, drainage, or irrigation on a county or community basis, and grazing associations are becoming very important devices for community action toward planning the use of the soil. During recent years many soil conservation districts have

been established in several states to deal with local problems of soil erosion, including flood control. Special assistance is given these districts by the U.S. Department of Agriculture, especially through a newly created bureau—the Soil Conservation Service. A great many less formal associations have been formed by farmers to deal with problems of increasing and maintaining soil productivity through the application of modern techniques. Perhaps the most notable of these are those sponsored and assisted by the Tennessee Valley Authority in cooperation with the State Extension Services. Recently, the Land Grant Colleges and the Department of Agriculture have developed a program for state and local planning, as a continucus activity, seeking to bring together expert and farmer opinion and coordinate the efforts of farmers and the various federal, state, and local agencies in terms of the needs of individual farms.

These are some of the more important social devices that have direct influence on the use of soil by individual farmers. Of course, the whole culture influences him and his activities indirectly. Only the most primitive farming could be done by individuals alone, and more and more during the past 100 years have farmers become dependent upon the activities of other people. Within the boundaries of his own farm he has many choices, but all of these depend upon the state of affairs outside of the farm.

We have already listed some of the more important factors that lie outside the boundaries of the farm, and hereafter are listed some of the most important considerations within the farm boundaries. Of course, it is not possible to separate them too sharply. A farmer who will not read or listen gets little directly from scientific re-

search, although many who think they learn nothing this way have followed what other farmers did, and thus received the results later and indirectly.

The whole problem of getting a farm in the first place, of proper size for good management according to the skill of the operator, and having soils adapted to the crops and livestock he wants to grow, is a borderline one. Some farmers have selected poor soil from want of knowledge, others because they could get nothing else. Many have farms larger than they can manage properly, or at least larger than they need. A great deal of the difficulty of small farm units on the soils of the drier parts of the country has come about through people moving from the podzolic soils of humid regions where family farms are relatively small to the semiarid regions where farms for the same income must be much larger, but they got one only a little larger. In humid regions, especially in the South, the pressure of an increasing population has pushed some farmers on to the poor soils. Also the development of machinery has made it convenient to farm large units with the same labor formerly needed for a much smaller farm. In this process, many tenants and share-croppers have lost the use of soil they had been used to cultivate. As farmers have died or lost their land from debts, small farms have sometimes been drawn into larger ones (Figures 79 and 80).

Thus we must always remind ourselves of the outside influences when thinking of the problems within farm boundaries:

1. The needs of the farm family for good food, shelter, water, fuel, and so on, should, perhaps, be put first. Even with the present emphasis upon cash sales, by careful planning of resources and time most farm families can

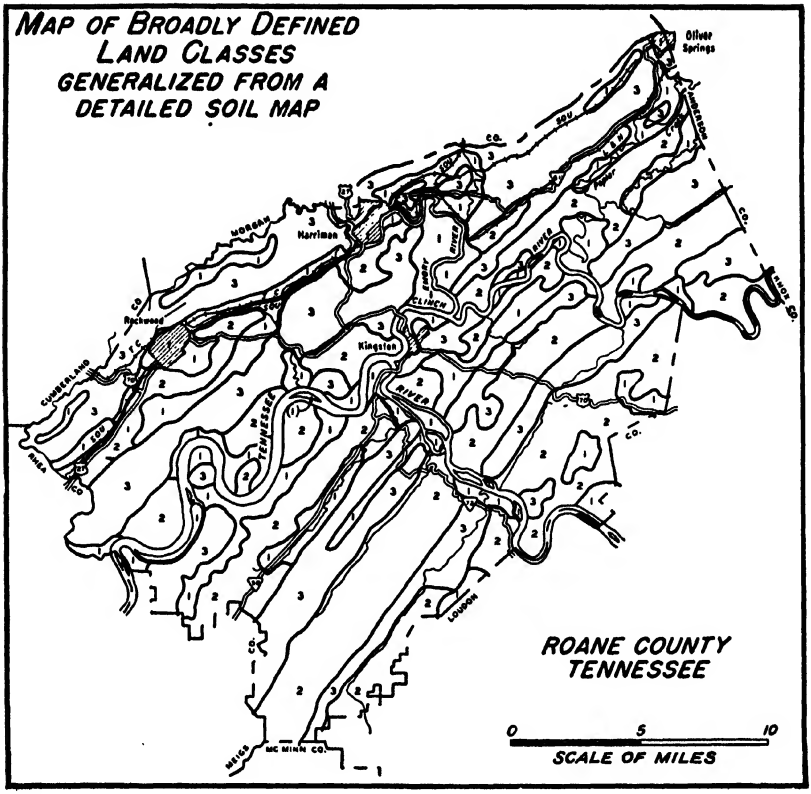

FIGURE 79. A map of broadly defined soil associations, generalized from a detailed soil map, is useful in area planning outside of farm boundaries. (Contrast with Figure 80.) The soils of this county were mapped in great detail on a large scale. Over 160 individual soil types and phases were recognized. These were first combined into 5 groups according to their capabilities for agricultural use as (1) first, (2) second, and (3) third grade soils for crops, (4) soils suitable for pasture but not for crops, and (5) soils suitable only for trees. Because of the sharp changes in parent rock and relief, two important factors responsible for soil formation, a map showing the distribution of these five groups is extremely detailed and must be of large scale.

In order to make a small-scale map showing the broad distribution of soils, areas of the different soils were grouped geographically into 3 associations defined briefly as follows:

Class 1 includes most of the first grade soils in the county and only a relatively small percentage of land unsuitable for agricultural use.

Class 2 includes a large amount of land suitable for pasture but not for crops, and significant but small percentages of the other groups.

Class 3 consists mostly of land unsuitable for crops or pasture, al-

produce a great deal toward their own support, especially those on the podzolic soils. During the boom period of the World War, many farmers ceased to raise their own gardens and orchards and bought everything. Many of the old farm skills of gardening, fruit growing, butchering, canning, etc., have been lost. Thousands of farm families could greatly increase their standard of living through the use of these skills. They have the time and soils that could be used without reducing the crops and livestock sold for cash. After all, something is seriously wrong when farm people on podzolic soils actually face starvation during years with normal weather.

2. The layout of fields and lanes should be planned with regard to the natural soil areas on the farm. The advantage of square or rectangular fields is offset by the great disadvantages of having several entirely different kinds of soils in the same field that require different practices, tillage at different times, and different crop rotations, and on which crops should be harvested at different

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though there are small tracts of the better soils in scattered areas.

The relative proportions of soils of the five groups according to their capabilities for use in each land class shown on the map are given in the following table:

	Group 1	Group 2	Group 3	Group 4	Group 5
Class 1	4.3%	22.9%	54.3%	11.4%	7.1%
Class 2	1.7	7.4	13.2	56.2	22.5
Class 3	0.8	1.9	5.1	7.5	84.7

Such a map is invaluable for determining the best location of farm-to-market roads, rural electrification lines, plants for processing agricultural products, and similar structures, as well as for the delineation of public forests and recreational areas, planning school districts and similar considerations that involve the county as a whole. The detailed soil maps must be generalized in this fashion for clarifying these broader relationships. (Courtesy of A. C. Orvedal, Division of Soil Survey.)

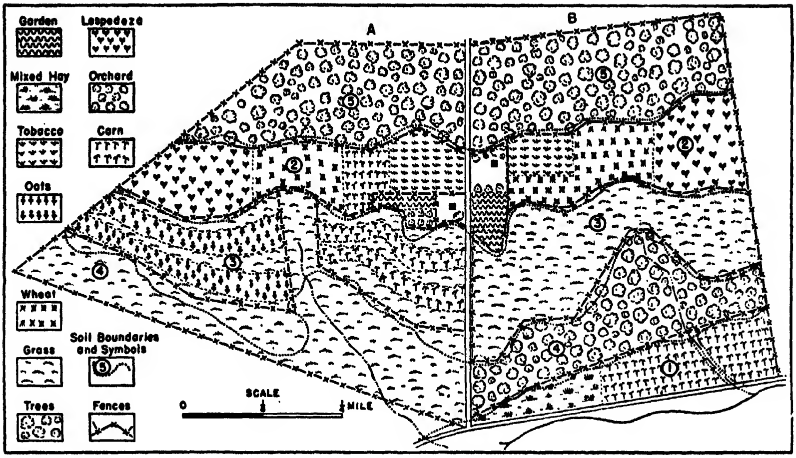

FIGURE 80. Detailed soil maps are used for planning within farm boundaries. These two adjoining farms in the ridge-valley region of Southeastern United States consist chiefly of relatively poor soils, although part of them can be used for crops with careful management, and one is very productive. In order to bring out also the influence of a small area of one particular soil type upon the others in the farm units, these drawings have been idealized. Each farm consists of about 140 acres. The soils on the two farms may be described as follows:

1. Huntington silt loam. Highly fertile soil of nearly level stream bottoms. Although occasionally subject to overflow for short periods, it is easy to till and there is little hazard from erosion. Crops suffer little from drought on this soil. If devoted to mixed hay containing legumes every third or fourth year and a little phosphate used, excellent crops of corn may be obtained.

2. Clarksville cherty silt loam. Soil with good physical condition for crops, but relatively low in fertility, cherty, slightly stony, and undulating or gently sloping. The soil is comparatively easy to till but care must be taken that legume hay crops are grown frequently, that the soil does not remain bare during the winter, and that tillage operations are conducted on the contour. In a few places strip cropping may be necessary for best results. Applications of both lime and phosphate, together with some potash, will be necessary for good yields. With legumes grown and manure properly conserved and applied, but little nitrogen fertilizer will be required.

3. Fullerton silt loam, rolling phase. Moderately fertile soil with good physical condition for crops, but slightly stony and strongly sloping. With applications of lime and phosphate good pastures with legumes can be grown easily. Crops can be grown with less fertilizer and lime than on soil No. 2, but great care to avoid excessive run-off and erosion must be taken through strip cropping and the maintenance of grassed areas in the drainage ways.

4. Fullerton cherty loam, hilly phase. Soil with fair physical condi-

periods. Some variations frequently must be tolerated but many fields give low yields because all the soils are treated alike to the disadvantage, or even extreme detriment, of some of them. Much serious erosion has been initiated, for example, by having straight fences and plow furrows without regard to the direction of slopes.

3. The combination of crops and crop rotation must be arranged in accordance with the needs of livestock for feed and pasture, the market facilities and prices that may be expected, the ability and skills of the operator, the availability of labor in the different seasons, the relative yields of the various crops on the different soils, and the needs of the soils for the maintenance of productivity.

Usually one rotation cannot be used for the entire farm. Some fields will have slightly different rotations than others, and all should be as flexible as practicable so that shifts can be made without wrecking the whole system in cases of drought or crop failures, or sudden changes in prices. Especially, where livestock is produced, it may be necessary to raise supplemental feed

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tion, quite stony, strongly sloping, and relatively low in fertility. Forest trees grow well on this soil and grasses for pasture can be grown through the use of lime, heavy applications of phosphate fertilizer, and careful management to prevent overgrazing and the formation of little rills that could easily grow into gullies.

5. Clarksville stony loam, steep phase. Soil so stony and steeply sloping that only forest trees can be grown.

A system of farming that will support a family and conserve the soil must include livestock and some cash crop. It is much more easily arranged on Farm B than on farm A because of the small area of soil highly productive for corn. On farm B, sufficient corn can be grown on soil No. 1 so that soil No. 2 can be used for tobacco, small grains, and legumes, soil No. 3 used for pasture, and soil No. 4 for forestry. Since there is no soil highly productive for corn on farm A, soil No. 3 must be used partly for corn or other feed crops and soil No. 4 for pasture with rather difficult management practices required in both instances. Soil No. 5 cannot be used for crops or pasture under any known system of management that would be practical.

crops should something happen to the main feed crops. Some soils have little leeway and may be used only for woods, or for woods or pasture. Certain fields may be devoted to fruit trees or other long-time crops. But the whole group of long and short rotation on each field must be so arranged as to give a fairly balanced result for the whole farm, year after year, and, as nearly as possible, a balanced labor demand during each year. Many farmers are badly off because they raise only a few crops that demand labor for short periods. During the remainder of the year the farmer has little of advantage to do. Most successful farms have the work load quite well distributed during the 12 months.[2]

4. The number and kind of livestock must be planned in accordance with the feed crops available, market facilities, and the skill of the operator. With very favorable market facilities dairy or poultry farms may purchase the bulk of their feed requirements, although suitable pasture and bulky feeds for dairy cows usually must be produced on the farm. Although it is possible to maintain soil productivity without livestock, on most farms it is much more easily arranged if some part of the farm plan includes the growing of pasture and feed crops for stock and if manure is available for use on the soil.

5. Sufficient power must be available for farm operations. In this respect, the truck, tractor, and automobile have wrought a near revolution by releasing vast acreages used formerly for other crops—acres that were to grow

[2] A well-balanced farm unit is perhaps most easily arranged on the Gray-Brown Podzolic soils, but this can also be done without much trouble on all the podzolic soils. The agriculture of the English tradition is one of great diversity because of the wide range of crops that can be grown on the Gray-Brown Podzolic soils. This agriculture is beautifully described in a little book of verse by V. Sackville-West, *The Land*. Even the Prairie and Chernozem soils offer much more opportunity for diversity than many farmers have developed.

feed for horses and mules. On many small and medium-sized farms where some horses must be used anyway, the purchase of tractors has been uneconomic since they could replace only a small part of the horses and mules needing feed and required a large cash outlay. Many farmers can market the products of their soil to themselves for power to more advantage than by making direct cash outlays for motor fuel. On large farms especially, the use of the tractor has greatly reduced the labor requirements per acre. Recently small tractors (with rubber tires) and machinery to go with them have been developed for the small farm and their use is increasing. One other advantage of the tractor lies in the speed with which soils may be plowed, making it possible to do the tillage at more nearly the best time from the point of view of the season and the moisture content of the soil.

6. Labor needs, on an annual and seasonal basis, as well as the work of the farmer and his family, must be taken into account. Many large farms have become so specialized that the problem of securing labor during the peak periods is difficult for the farmer, and seasonal employment, requiring periodic moving, is unsatisfactory to the laborers. Had this difficulty been foreseen, more diversification, both by farms and by communities, could have been arranged in California and other places where the problem is becoming acute. Plantations and other large farms producing crops like citrus, sugarcane, bananas, pineapples, and vegetables, which have been able to develop a plan calling for nearly steady work throughout the year, have an enormous advantage, at least from a social point of view, over those using labor only in peak seasons. This is one of the chief advantages, for example, of the sugar plantations in Hawaii over the pineapple

plantations there and over the sugar plantations in Puerto Rico. Reasonably steady employment of agricultural labor, either on individual farms or in communities, in order to avoid the continual migration of the laborers and their families needs to be arranged. On a small farm, if the farmer can arrange to spread the work throughout the year, he can often avoid the cash expense for labor during peak periods.

7. The use of lime and fertilizers must be arranged for in relationship to the deficiencies of the soil, the crops to be grown, the legumes and green manures in the rotation, and the manure available from livestock. The labor of the farmer and the benefits of other good practices may be lost because of an unsupplied need for lime or phosphate, or for some other fertilizer. Except for orchards or some other special crops, the whole rotation must be considered. In a rotation of corn, oats, wheat and clover, for example, one may apply lime and manure just before the corn and phosphate just before the wheat, but these treatments influence all the crops.

8. Special practices for water control—irrigation, drainage, and control of run-off and erosion—must be fitted to the other practices. The construction of terraces on sloping land without lime or phosphate where these are needed and without closely-growing legumes or grasses in the rotation may be a great waste. The whole matter of control of run-off is largely one of properly arranging fields and cropping practices, sometimes supplemented by terraces, check dams, and similar structures where needed.

In summary, planning the use of the soil involves the fitting together of a complicated set of economic, social, and physical conditions to a simple or highly complex soil

pattern on individual farms. Each is an individual problem, with its own peculiar set of relationships. The fact that the soil is fixed, immobile, and that the home is an integral part of the unit of operation and management, sets off farm planning as something quite unlike the planning of a strictly business enterprise or an industrial plant. Always the farmer does his planning within a framework of community, state, and national laws, customs, and techniques that may make it possible for him to plan successfully or may prevent it.

If the farmer knows what plants the soils on his farm can produce, the yields that can be expected under different management practices, and the effect of the several practices on the long time productivity of the soils, he can then select from all these alternatives the ones best suited to make the farm as a whole successful. A great deal of this basic knowledge of the response of his soils to management grows out of his own experience and that of his neighbors. During recent years, soil scientists have been able to add to this knowledge through their researches and surveys.

18.

SOIL AND OUR FUTURE

THE soil is the meeting place of the living matter at the surface and of the mineral matter beneath the surface, and of the atmosphere above and the solid rock underneath. Essentially all living matter depends upon it, directly or indirectly, is, in fact, a part of those very processes that produce the soil upon which life depends. Plants and soils have grown up together, each partly a cause of the other. Man has had somewhat the same relationship to the soils. He finds some are better suited to his needs than others. He may change them either for better or for worse.

Five principal factors define any natural landscape and the formation of the natural soil: (1) climate, (2) vegetation, (3) relief, (4) rocks, and (5) age. Each of these has its influence, merged with the influences of the others. The soil of any place represents the effect of all of them, working together. From the point of view of geography, soil types are then landscapes, classified and named on the basis of the soil produced on them. To say Chernozem or Miami silt loam is to mention two landscapes—the first a very broadly defined one, found in large areas on several continents, the second a narrowly defined one found on gently sloping calcareous glacial till in temperate forested regions, in small areas among areas of other soils. The

expression Miami silt loam[1] refers to a particular combination of climate, vegetation, relief, parent rock, and age just as much as it does to the color, thickness, structure and other characteristics of the several soil horizons and their arrangement in the soil profile. Thus when it is said that certain crops grow well on some soil, or that a particular type of social economy is adapted to some soil, the climate and other features of the landscape are involved just as much as the material in which the roots grow.

Already we have seen the great differences among the many soils—differences that require equally great variations in the way men use them, or in the way they adapt themselves to them, both as individuals and as races. First of all, man gets his food from the soil. Some are high in such minerals as calcium and phosphorus—others are low. Among primitive societies, rural people live close to the soil, get their food from close at hand, and change it little. If the food is low in minerals or iodine, for example, they must get along with little. Over the centuries those persons who could thrive best on the soil would have the greatest chance to live and have children. Their type would succeed over the years better than other types. Some believe these facts have been very important in developing the different races and types of people in the world. Probably the direct physical effect of the soil through the food supply has been important over the long centuries. Just how important, it is difficult to say because modern man has moved about a great deal during the past few centuries. He has been a trader and has eaten food from many soils. Part of his foods are so

[1] Defined in Appendix I.

carefully prepared that some of the more important minerals are lost. By polishing rice and removing the bran from wheat, for example, modern man has satisfied his taste but greatly lowered the content of essential minerals in his food.

At least people cannot always change their food suddenly without bad results. Many native peoples in the high mountain valleys, in the South Sea Islands, and in other remote places who had good teeth and good bones, began to suffer all sorts of physical difficulties when they substituted modern man's sugar, white flour, and lard for their native foods. Many diseases of animals have been traced directly to a lack of phosphorus, calcium, iodine, cobalt, or other necessary elements in the food. Although studies in this important matter have scarcely more than begun, many of these animal diseases have been traced to the soil, and some human diseases as well. So many factors may cause people to have ill health that careful research will be necessary to discover just what diseases are traceable to soil and how different soils need to be handled to overcome them. Now we know that there is a vital relationship, a great gain has been made.

Man lives for much besides food. An ancient Greek once said, "If I had two drachmas, one I would spend for bread, and the other for hyacinths." The landscape of any place has a deep influence upon the artistic expression of people. The slow, monotonous music of the plains or steppes stands in contrast to the sharp variations of that from the mountains, or the rhythm of the tropical jungle. The careful detail of the English novelist somewhat suggests the detail of the landscape of forested regions clothed with small fields and farms. The Russian novelist paints with a broader brush, with wide sweeps, suggestive

of the steppes themselves. The Parthenon on a hill at Athens, in the dry nearly open landscape, has inspired artists and laymen alike for centuries. But a replica built in an American city in a humid forested landscape seems somehow out of place.

One who has lived on the plains or steppes feels the forest to be a place enclosed, a prison. Yet one from the forest seems exposed, lonely, on the plains. How the people, the women especially, who came from the podzolic soils of the East to the treeless Chernozem and Chestnut soils of the plains suffered from loneliness! Those who have homes—places where they have lived during their childhood—find new landscapes interesting, but sometimes strange. It is restful and quieting to return to the same kind of landscape with which one is accustomed. Such expressions as "the horror of the jungle," "the mystery of the steppe," and "the grandeur of the desert" express the strangeness of these landscapes to their authors from the temperate forested regions. Perhaps they do not realize that their own landscape is oppressive to the stranger. In the United States there are a great variety of soils, of landscapes. No other country has greater contrasts, and in no other country have the roads and other conditions permitted such a large percentage of the people to travel. Some hold that the peculiar characteristics of the Americans are due in part to this movement from landscape to landscape. It may account for some of our nervousness, tension, and hurry—whether there is any reason to hurry or not.

This individual influence may be even less important than the social influences. On different soils, people must use entirely different methods not only as individual farmers and gardeners, but also as communities. In the

last chapter we mentioned several of these—the size of farm, the crops grown, the transportation system, and so on. Life in the Podzol region where the soils must be cleared of forests, are naturally infertile but responsive to careful management, and can support many kinds of crops, where the winters are long but where droughts are rare, and where fuel and water are abundant—life here on the family farm is quite different than on the Reddish-Chestnut soils of the warm subhumid plains or in the desert.

Not only do people live differently on these different soils—they must live differently to live at all. When the Spanish came to the Southwest, they found things not altogether unlike what they had known before. Perhaps some of the characteristic living patterns in the Southwest today are not so much due to the fact that the early settlers were Spanish, as to the environment. Especially did the English who came to the American colonies find soils similar to those of their homeland. English common law and English customs were easily adapted to the New World. As time went on differences arose to be sure, especially between those on the Gray-Brown Podzolic soils of the north and those on the Yellow and Red Podzolic soils of the south (see map in Figure 63). Unfortunately, these differences in needs and in points of view finally led to a terrible war between the states of the north and those of the south. From this war and the period that followed, the southern communities have not recovered entirely. It may be hoped that this war can be seen as a failure of political leadership to visualize the necessary balance between national unity and local autonomy. One cannot expect that social arrangements will be the same over the whole country on the different soils. People on any soil

must have sufficient freedom to adapt their ways to the local conditions, else the people and the soil both are bound to deteriorate.

As people from eastern United States and especially from Europe moved to the prairies and the plains—on to the Prairie, Chernozem, and Chestnut soils—they found things entirely different in many respects. English common law and other customs had to undergo many changes. The period of so-called lawlessness of the west was just such a period of adjustment to the new conditions. The traditions that the people brought with them, and the farming practices, had to undergo change. This change is still going on and no one knows the outcome definitely because no one knows just what type of farming is best suited to the Chestnut and Brown soils. Certainly it is not grain raised year after year, or simply alternated with fallow, in small farm units. But it is doubtful that these soils all must go back to grass. There is some middle ground, some combination of farming and grazing, with supplemental irrigation, that has not been found. Now farms are too small in many places, and taxes and electric power rates too high, for families to make a go of things. The people on these soils, like those on other soils, must work out a social pattern for themselves that will lead to secure production.

The older civilizations developed largely on one general type of soil: the Egyptian on the alluvial soils along the Nile; the Classical (Greek-Roman) on the red (Terra Rossa) soils around the Mediterranean Sea; the Arabian on the soils of the deserts and semi-deserts; and the Western (ours) on the light-colored, forested soils (mostly Gray-Brown Podzolic) of western Europe, northeastern United States, eastern Canada, parts of Australia, New

Zealand, South Africa, and elsewhere. Other soils in smaller areas were associated with each culture, and each spread over other soils but, by and large, the homeland of each culture was on one landscape. Each appears to have gone through a long period of slow growth, first on the land or in country towns, then more rapidly in cities, reached a sort of "height" or climax, and then decayed. The period of decay was short or long, depending in part upon the vigor of competing peoples. Roman culture had passed into decay, it is said, long before any other people really attempted to give it the final "push." Others, like the Arabian and Incan, were cut short.

In the beginning, the people of each of these great cultures lived close to the soil. Great cultural ideas seem to be born in the nursery of unspoiled rural landscapes. It is in the city that styles and dogmas develop, but the course is set before cities are built, by men with roots in the soil. The small towns of a young culture are primarily rural, but cities are not. To the countryman cities seem to be conscious creations of men, of men without roots, who have grown apart from the soil. The emphasis of the city seems to be more upon engineering, money, and power, than upon living and growing. The change from the nearly self-contained farm of the early Colonial period to the modern specialized farm is partly a result of city ways in the country. The "business of farming" has replaced the "art of agriculture." "Soil" becomes "land" or real estate. The cities not only tend to dominate the people on the land through their control of finances and politics, but country people now look to the city for nearly all education, culture, and amusement. The old country play-house has given way to the city movie.

If one studies the history of the people, not just of the

leaders, of the several older civilizations, there are a great many similarities between our civilization now and that of the others just before they finally went down. There are similarities in the attitude of the people toward religion, politics, art, morals, and business. In early Rome there were many free-holders—farmers. As time went on the farms became larger, grew into estates, and a large class of landless people came into existence on Roman farms. Something of the sort may be happening, slowly, today in the United States. Thousands of families, share-croppers, have been shoved off the soil they once farmed to look for work or land where there is very little of either to be had without money or education.

The large estate or plantation represents a concentration of skills in the hands of a few, while the rural community of small free-holders represents the widest distribution of agricultural skills. Although the concentration of skills may bring efficiency of production, as on many tropical plantations, it hardly leads to democracy, at least not to the kind of democracy people have known before.

There is no question but that soil productivity has declined in United States during recent years, by no means everywhere, nor as much nor for the reasons that occasional panic-makers have said. Because soil erosion was neglected for many years is not sufficient reason, of course, for exaggerating it now. In fact it is serious enough as it is—exaggeration is unnecessary. More often, however, erosion is a result, a symptom, rather than a cause of rural distress and declining soil fertility. This decline in productivity has happened partly because of the inability of the people in some regions to establish a satisfactory type of farming. On some soils this seems to have been due, in part at least, to the domination of the

people in one area by those elsewhere, like those on the Red Podzolic soils of the South by people in other regions. On others it has been due to people attempting to force a pattern of use on new soils that is not suited to them as on the Reddish-Chestnut soils of the southern plains. It is of the utmost importance to realize that the decline in productivity is a symptom of the social problem, not the cause of it. The remedy for soil depletion must come along with a remedy for the social problems that are responsible. Soil erosion is an important symptom of bad relationships between people and soil, just as a headache is often a symptom of some more fundamental illness. Civilizations can hardly be said to have declined from soil exhaustion—soil exhaustion is more a result of the decay of the people, of the civilization. The soils of Italy, for example, likely were producing more in 1939 than ever before.

Despite the evidences of decline, history does not always repeat itself, and social decline is not inevitable. There are some differences between conditions now and those just before the decline of other civilizations, chief among which is the great development of science. Of course, science may be used to hasten the decline, but it can be used to work out methods of farming for the different soil types that will lead to secure production. Of equal importance, the methods and approach of science can be used to study the relationship between the soil and the people in order that economic and social arrangements can be made that will permit the farmer to follow good practices. Now that the land of the New World is nearly all settled some way must be found to resolve conflicts between groups of people and between regions. There is no West where the discontented may go. There

are many complicated relationships among groups of farmers, groups of labor, groups in business. There are sectional conflicts as well, some of which cut across the other lines. These may be examined by careful scientific study, and principles can be established for the development of a changing pattern in which all can live, without starvation, wars, and disease. To be sound, the individual farmers must take a part in the study and assume a responsibility in the formation of laws and cooperative devices for mutual assistance. Unless they do this, planning the use of the soil for the future could become autocratic, managed by a few people according to their personal ideas, which may or may not be fundamentally sound for the whole country.

The future of the soil and the people together is very hard to predict. Through the aid of science a secure relationship can be established. Much remains to be found out, but the general outlines of soil science are becoming clear. Of utmost importance is the recognition that different soils must be treated differently, not only plowed and fertilized differently, but the social and economic patterns of communities must be different. This does not mean that there is some very precisely fixed pattern for each soil region. Each offers much latitude, to be sure, for response to other influences in the culture, some more than others.

As trade and industry become more complicated there seems to be a tendency in the United States toward federal centralization of power. Of course, the central government must have power to deal with these broad problems, and can exercise it without central administration. If the people in the United States develop decentralized administration with full cooperation of the

local citizens as, for example, in county agricultural planning committees, in the educational system, and in similar programs, planning to satisfy both local and national needs can be done with the aid of science. Strong centralization of power and planning, with a weakening of local responsibility, in an attempt to develop uniformity in a country with many soils, might lead to the exploitation of some sections; then poverty and soil depletion would follow. Even centralized planning for protection of the soil could have the effect of increasing the problems of soil depletion.

Soil science has a contribution to make toward the future. But certainly not alone. As science itself has become so specialized, it is difficult to see science as a whole and its relationship to politics, art, business, and agriculture. More and more modern education seems to make people specialists—members of a group or clique—and lead them away from the masses, from real democracy. The kind of science that is super-specialized cannot lead people to better relationships with each other and the land. Neither can the so-called "pure" science, too cold or too snobbish to face the real problems. Some see a danger that farmers as well as other people may turn their problems over to some special group, some special bureaucracy, rather than think out the problems for themselves and make their decisions by the democratic method.

There exist abundant supplies of nearly all natural resources in the United States and especially of soil. Enough injury to the soil has taken place locally here and there to indicate a pressing need for adjustments of agricultural people to the soil upon which they live. Since there are many, many soils these relationships are too

complicated to be resolved by a few simple slogans or programs. Many things can be done, differently on different soils. Just as the natural soil is a complex and individual combination of many characteristics and many natural forces, so the use of the soil by a strong, healthy, and vigorous people is the result of a particular combination of many individual, community, provincial, national, and international actions. Strong centralization, at the expense of local responsibility and leadership, with trends toward uniformity throughout the country, will lead, as in the past, toward serious sectional conflicts, increasing rural distress, and soil depletion.

Industry has developed greatly in the United States as well as agriculture. Industry cannot thrive under strongly self-sufficient nationalism unless there are a wide variety of soils, as in the United States, or the Soviet Union, or unless there are colonies on other soils. Because of large areas of Chernozem, Chestnut, and similar soils specialization is essential in the United States. Sectional interests will always create problems, sometimes problems that will place severe strains on the pattern of government. Yet the very existence of our kind of government depends upon the complementary specialization in industry and agriculture made possible by the great variety of soils. In America there are so many soils that if a proper balance between national solidarity and local autonomy is maintained a wonderful opportunity exists for a rich, colorful, and strong national life. There is no place for either thoughtless optimism or blind pessimism.

If by liberalism one means a system of economic and political institutions that gives the greatest opportunity for individual self-development without special privilege to any; and if by science one means the objective unbiased

study of our environment and our relationship to it and to one another, in order to predict the results of actions; then the perfection of these two concepts must lead to a secure future for both soil and people. Science without liberalism could ruin us quickly, and liberalism without science lead us more slowly to final decay; but given the resources of America, as long as these two concepts are dominant together we shall find strength and happiness.

APPENDIX I

SOIL CLASSIFICATION AND SOIL MAPS

As any science grows, some plan or system of classification must be devised if the facts are to be remembered, their relationship to one another understood, and their application to practical problems made possible. Perhaps it is not so much the facts themselves that are used directly in planning the use of the soil as the general principles derived from the facts. As with plants, animals, and rocks, soils are defined and arranged into suitable categories or "pigeon holes." We must constantly remind ourselves that there are few sharp lines in nature—there are some "blacks" and "whites," but between them are many more "grays." Thus, a system of classification is purely a human invention, subject to human error, and its accuracy and usefulness depend upon what people know. For this reason systems of classification change, should change, as knowledge grows; they are a convenience, and should never become so rigid that new facts cannot be used to amend them.

There is a fundamental, natural system of soil classification, developed over the years through the combined efforts of many people. Even so, it is still young—much younger than those in chemistry and botany—and will, of course, be changed and improved as time goes on and more new facts are found and relationships conceived. There are many other special classifications, based upon this fundamental one, for certain specific purposes. Thus, soils may be grouped according to their need for lime; their ability to produce corn, sugarcane, peanuts, oak trees, or other plants; their susceptibility to erosion when used in different ways; and so on, provided their place in the fundamental system is known. This requires specific knowledge.

The first really important attempts to classify soils were made on a basis of geology. Some of these were useful classifications of parent materials, but not of true soils. A great many entirely different soils may be developed from identical

parent material, depending upon the other factors of soil formation—climate, vegetation, relief, and age. In the United States there are areas all the way from north-central Montana to the Maine coast having soils developed from very similar, or even identical glacial drift, but many of the soils have nothing except parent material in common and vary from one another in nearly all their most important characteristics.

The first recognition that each soil has a distinct profile came in Russia about seventy years ago. In that vast country scientists noted that the boundaries between climatic types, vegetation types, and continental soil types, or great soil groups, were parallel. They developed broad soil groups, based upon soil profiles. Detailed soil study had been going on for some time in the United States. Immediately after the World War the results of the Russian work became available to western Europeans and Americans. The influence was tremendous and since that time, the recognition of the soil profile as a basis for classification has become firmly established and, at the same time, local features of slope and parent material, are recognized in the definition of local soil types within the great soil groups.

The system of classification, as now used in America, has the following categories from the lowest to the highest. Examples of names of recognized groups within each category are given on the right, starting with an example of the lowest and giving names of succeeding higher categories in which it belongs.

Name of Category		*Example*
0. Phase	:	Bellefontaine loam, slope phase
I. **Type**	:	Bellefontaine loam
II. **Series**	:	Bellefontaine
III. Family	:	Miami
IV. **Great soil group**	:	Gray-Brown Podzolic
V. Suborder	:	Light-colored podzolized soils of the timbered region
VI. Order	:	Zonal soils

The categories in bold-faced type are the most important. On small-scale maps of large areas, such as continents, the great soil groups are the units shown. On detailed soil maps the local units, series, type, and phase are shown. There are several thousand of these local units. The soil type is the basic unit in classification.

In Appendix II, *Descriptive outline of great soil groups,* the great soil groups are each defined in relationship to their environment and to one another. Here the local soil types will be dealt with from the point of view of detailed soil maps, such as those published for many counties in the United States.

SIMPLE UNITS OF CLASSIFICATION

Three units are employed in the classification of soil in the field: (1) series, (2) type, and (3) phase. The simple units are not always mappable, since one soil type may exist in such small areas in association with one or more other soil types, that the whole group of soil types will need to be shown on the maps as a *complex,* defined as consisting of certain soil types, or phases, in a particular pattern. Thus, whether or not the strictly taxonomic (classificational) units—series, types, or phases—are mappable as such depends upon the size of individual areas and the scale of the map. In most parts of the United States these simplest units cannot be shown separately on maps of a scale less than 1 to 2 miles to the inch, although there are a few exceptions in places where soils are nearly uniform over large areas. There are many other instances, as in most of the humid, hilly regions where even at 2 or 4 inches to the mile, some of the soil types and phases must be shown as complexes.

The soil series is of first importance. It is defined as a group of soils having the same genetic horizons (that is, horizons produced by processes of soil formation) similar in important characteristics and arrangement in the soil profile, and all developed from one kind of parent material. Except for the texture of the surface soil, or A horizon, the texture of the other horizons, and the color, structure, content

of humus, and reaction (acidity or alkalinity) of each horizon are similar for all soils within a series; although some range in these internal characteristics, and in the external characteristics of slope, degree of erosion, if any, and stoniness must be permitted. Thus, the definition of a soil series includes a description of the internal and external characteristics, and their range. In some soil series the range in slope or in the thickness of the horizons is very small, while in others there is some considerable variation. That is, a soil series may have a range in slope that has little significance to the native vegetation or to the development of the soil profile, but when plowed and put under cultivation, a part of the soil will have practical differences in slope from other parts. These differences are indicated as subtypes or *phases*.

The soil series are given names chosen from place names near the spots where the series are first defined, such as Miami, Hagerstown, Mohave, Houston, and Fargo. Some of the series defined and shown on maps in the early stages of soil classification, many years ago, were given such broad definitions that it later became necessary to split them into several series as the soils were studied more carefully. Thus, several soil series are now recognized for soils included with the Miami and Carrington as first defined.

Several thousand soil series are recognized in the United States. Many of these also occur in other parts of the world because, of course, each combination of climate, native vegetation, parent material, relief, and age, produces the same soil. But there are a very large number of significant combinations of these factors and a great many soil series. Many series like those included in a family, differ from one another in only some relatively minor characteristic; while others are entirely different from one another, like those in different great soil groups. Even between two great soil groups, series representing transitional soils may not be greatly different, or they may be entirely unlike one another.

As examples, there follow a few typical, technical descriptions of important soil series, developed by generalization from a great many descriptions of individual profiles. In

soil survey reports these descriptions are greatly expanded to explain the crops that may be grown and their response to cultural practices. In detailed studies of soil morphology and genesis, each soil profile examined is precisely described in much greater detail. The descriptions that follow are the kind used in the classification work, broad enough to include the members of the series and detailed enough to set the series off from other related series.

Miami Series: The Miami soils are representative of the Gray-Brown Podzolic soils of the Middle West, developed from calcareous glacial till. The similar Russell soils are distinguished from them by a greater degree of weathering of the parent material, greater depth to lime in profiles of equivalent textures, and in their geographic distribution to the south of the belt of Miami and associated soils.

I. Soil Profile: (Miami loam)

1. (A_0) Leaf mold from deciduous trees, decomposed at base; nearly neutral reaction; 1 to 3 inches thick.
2. (A_1) Grayish-brown loam; organic matter high at top, decreases gradually; nearly neutral reaction; 2 to 4 inches thick.
3. (A_2) Light-yellow to yellow-gray loam; medium to strongly acid; 7 to 12 inches thick.
4. (A–B) Transitional layer 2 to 6 inches thick.
5. (B_2) Yellow-brown heavy clay loam; sticky when wet, hard and readily broken into coarsely granular fragments when dry; slightly or medium acid in upper portion, neutral or mildly alkaline near the base; 15 to 25 inches thick.
6. (C) Glacial till, consisting of a heterogeneous mixture of all textures from clay to stones, of varying mineralogical composition but with sufficient lime present in the mass to produce general effervescence with hydrochloric acid, and with a marked percentage of limestone and dolomite pebbles and stones. Sufficient fine material is present to impart a general clay loam or loam texture.

II. Variations: The variations in this type are mostly in texture of the A horizon. In mapping this soil, many small

areas of sandy loam, fine sandy loam, and silt loam are necessarily included.

III. Topography: Generally undulating or rolling; often occupies the higher, better-drained areas on an undulating terrain.

IV. Drainage: Surface drainage good; internal drainage fair or good.

V. Natural Vegetation: Deciduous forest of white oak and hard maple.

VI. Use: General farming; corn, wheat, oats, hay, pasture. Valuable farm land, mostly cleared and cultivated.

VII. Distribution: South-central Michigan and adjacent parts of Indiana and Ohio.

Type location: Eaton County, Michigan.
Series established: Montgomery County, Ohio, 1900.

Carrington Series: The Carrington series includes Prairie soils developed on leached glacial till, mainly of the Iowan glaciation. These soils have a very dark grayish-brown A horizon, a yellowish-brown or brown B horizon, and a C horizon of leached glacial till. They differ from Tama soils, which have reached about the same stage of development, in having a substratum of glacial till instead of loess, and from Clarion soils in having no free lime to a depth of 5 feet or more.

I. Soil Profile: (Carrington loam)

1. (A_1) Very dark grayish-brown loose, mellow, fine granular loam; strongly acid; 10 to 14 inches thick.
2. (A_3) Transition layer, ranging from granular, very dark grayish-brown loam or clay loam in the upper part, to massive brown clay loam in the lower part; strongly acid; 8 or 10 inches thick.
3. (B) Brown or grayish-brown clay loam slightly heavier than the layers above. The material is well oxidized and leached of carbonates; slightly acid; about 20 inches thick.
4. (C) Brown or yellowish-brown clay loam splotched with yellow and rust-brown; contains a few boulders and pebbles. This is partially decomposed glacial till, oxidized and leached of readily soluble material to a depth of more than 5 feet; neutral or mildly alkaline.

II. Variations: The surface layer varies in thickness and darkness with the degree of slope. A thin covering of loess may have added to the composition of the more silty types. Occasional boulders and gravel are scattered over the surface of these soils and through the soil section. The areas in Nebraska developed from Kansan till have heavier subsoils than those on the Iowan drift.

III. Topography: Undulating or rolling.

IV. Drainage: Both surface and internal drainage are good.

V. Natural Vegetation: Tall prairie grasses.

VI. Use: General farming; corn, oats and other small grains, and tame hay crops; one of the best soils in the Middle West for corn production.

VII. Distribution: Iowa, Minnesota, eastern Nebraska, Illinois, and western Indiana.

Type location: Buchanan County, Iowa.

Series established: Carrington Area, North Dakota, 1905. The name "Carrington" was first given to soils in this area in 1905, and for a time all dark-colored soils developed on glacial drift were placed in this series. Later this general group of soils was subdivided into several series and the name "Carrington" was restricted to its present use. The soils first given the name are now correlated with the Barnes series.

Mohave Series: The Mohave series includes large areas of Red Desert soils in the arid Southwest. They are characterized by reddish-brown noncalcareous surface soils, underlain by compact, comparatively heavy, red subsoils and compact lime layers of mottled gray and red color, more or less cemented by lime. The Mohave soils have been developed in desert valleys on old alluvial-fan and terrace deposits that apparently have been subject to long periods of weathering and soil development. The materials are derived mainly from granite and other quartz-bearing crystalline rocks. These soils occur where the mean annual precipitation ranges from about 3½ to 12 inches, with mild, sunny winters and very hot summers. The Mohave soils are similar to the browner and less red Adelanto soils, and somewhat similar to the Tubac soils that have a Solonetz-like B horizon and a more cemented lime layer.

I. Soil Profile: (Mohave sandy loam)

1. (A) Brownish-red noncalcareous fine granular sandy loam. It has a distinct gritty feel due to angular and rounded coarse sand particles. About 7 inches thick.
2. (B_1) Red or light-red, slightly compact, noncalcareous or feebly calcareous gritty loam. About 7 inches thick and grades into
3. (B_2) Reddish-brown, compact, highly calcareous clay loam that is highly mottled with gray lime flecks. About 15 inches thick.
4. (C_c) Gray or brownish-gray, highly calcareous, compact, gritty loam that is weakly cemented with lime. This material, when wet, crushes easily to a structureless mass. About 50 inches thick.
5. (C) Grayish-brown, friable or loose fine gravelly loam and coarse sand which is highly calcareous but free of lime mottles.

II. Variations: In some areas the surface soil is calcareous. Where these soils grade into the Adelanto soils they have a less red surface soil. The degree of cementation of the lower B horizon varies from place to place; in some places it is quite definitely consolidated, whereas in other places it is only very slightly cemented. As previously mapped, the Mohave soils include areas that would now be differentiated as other soil series. Many areas have a distinct desert pavement underlain by a thin crust and a vesicular layer.

III. Topography: Occupies sloping old alluvial fans and high terraces that in places are rather undulating and where cut by drainage channels have steep slopes.

IV. Drainage: Surface drainage is generally good. Areas that have desert pavement may have excessive surface drainage and very poor penetration of water. The lower compact subsoil restricts rapid percolation.

V. Natural Vegetation: Widely spaced creosote bush, other desert shrubs, and cacti. Short-lived annuals grow in early spring and soon disappear.

VI. Use: Virgin areas are used only for range land, which has very low carrying capacity. Irrigated areas are planted to alfalfa, cotton, citrus fruits, vegetables, and other crops.

VII. Distribution: Southeastern California and the southern parts of Nevada, Arizona and New Mexico.

Type location: Buckeye-Beardsley Area, Arizona.

Series established: Middle Gila Valley, Arizona, 1917.

Holdrege Series: The Holdrege soils are normal Chernozems of the loessial uplands. They differ from the Marshall soils chiefly in having a layer of lime enrichment in the subsoil; from the Keith soils in having thicker and darker surface layers; and from the Hastings soils in having more friable subsoils. They are identical in features of the solum with the Hall soils that occupy stream terraces.

I. Soil Profile: (Holdrege silt loam)
   1. (A_1) Very dark grayish-brown mulch-like silt loam; noncalcareous; about 2 inches thick.
   2. (A_{11}) Very dark grayish-brown friable silt loam with either a fine-crumb or an imperfectly granular structure; noncalcareous; 8 to 12 inches thick.
   3. (B_2) Dark grayish-brown silt loam or light silty clay loam; slightly heavier than that of any layer above or below, but remains friable throughout; breaks naturally into large ill-defined prisms and irregular-shaped clods; noncalcareous; about 12 inches thick.
   4. (B_3) Grayish-brown transition layer of friable, massive or cloddy silt loam; noncalcareous; about 10 inches thick.
   5. (C_c) Light grayish-brown friable and massive silt containing an abundance of finely divided lime; grades to
   6. (C) The parent loess, a light yellowish-gray floury and limy silt.

II. Variations: The thickness of the surface layer and the depth to lime vary considerably with differences in relief.

III. Topography: Undulating or strongly rolling.

IV. Drainage: Both surface and internal drainage are everywhere adequate. Rapid run-off causes considerable erosion of unprotected soil on the more rolling phases.

V. Natural Vegetation: Mixed tall and short grasses, including big and little bluestems, grama, and buffalo grass.

VI. Use: Nearly all areas of these soils are cultivated; corn, wheat, oats, rye, and alfalfa are the principal crops.

VII. Distribution: Central and south-central Nebraska and the adjacent parts of Kansas.

Type location: Phelps County, Nebraska.

Series established: Phelps County, Nebraska, 1917.

Pullman Series: The Pullman series consists of smooth, deep dark soils in the Reddish-Chestnut soil zone in the High Plains areas of northwestern Texas and adjoining States. They are associated with the Richfield and Zita soils, but are less dark-colored than the Richfield soils and are deeper and more mature than the Zita soils.

I. Soil Profile: (Pullman silty clay loam)
   1. (A_1) Dark-brown silty clay loam; noncalcareous; crumbly; about 6 inches thick.
   2. (B_1) Dark-brown or dark chocolate brown clay; crumbly; noncalcareous; prismatic structure; 12 to 18 inches thick.
   3. (B_2) Brown calcareous clay; small cubelike particles separate when dry; about 12 inches thick.
   4. (B_3) Reddish-brown or reddish-yellow crumbly clay; upper part has cubelike separation; about 12 inches thick.
   5. (C_c) Calcareous buff-colored friable clay containing a large amount of soft calcareous carbonate in lumps—the layer of lime accumulation; 12 to 18 inches thick.
   6. (C) Parent material of buff or pinkish-buff calcareous friable clay; porous; contains small amount of soft lumps of calcium carbonate; many feet deep.

II. Variations: Silty clay loam is the chief type, but there is some fine sandy loam and loam. Soil layers are darker on the nearly flat areas, and the slight red color more apparent where there are gentle slopes.

III. Topography: Nearly flat or undulating plains.

IV. Drainage: Slow, but adequate in most places.

V. Natural Vegetation: Largely buffalo and grama grasses.

VI. Use: Largely for small grains, chiefly wheat and grain sorghums; stock farming; and range livestock. Soils are highly productive when moisture is adequate.

VII. Distribution: High Plains section of the Great Plains province, largely in northwestern Texas, Oklahoma, and northeastern New Mexico.

Type location: Potter County, Texas.

Series established: Potter County, Texas, 1929.

The soil type is the principal, basic unit used in detailed soil mapping and other soil studies. The definition is the same as that of soil series, except that the texture of the surface soil or A horizon is not allowed to vary significantly. Thus, there may be two soil types, let us say, Miami loam and Miami silt loam, in one soil series—the Miami series. The important difference between the two is the texture of the upper 6 to 10 inches.

The class name of the A horizon (or average of the surface soil to a depth of 6 to 8 inches in soils with poorly developed profiles), such as sand, loamy sand, sandy loam, loam, silt loam, clay loam, silty clay loam, clay, or silty clay, is added to the name of the soil series to give the complete name of the soil type. If the sand is fine or very fine, or if the soil is stony, cherty, or gravelly, the proper adjective is added to the soil class name. Thus, there is Clarksville cherty silt loam, Ottawa loamy fine sand, Rodman gravelly loam, Gleason stony clay loam, and so on. As soils have been studied more and more, the definitions of soil series have become more precise with fewer types in a series. This is to be expected, for one would not expect soils to have wide differences in texture without other very important differences as well. Exceptions are very young soils, especially those developing from recent alluvium. Since these have almost no developed profile and a narrow range in slope, several soil types may be included in one series.

A phase is a subdivision within soil type. The definitions of soil types restrict their external characteristics [1] as well as the internal or profile characteristics. Within the range per-

[1] That is, it is redundant to say that some area has a certain soil *and* a certain slope, since slope is included within a proper definition of soil type or phase.

mitted of slope, erosion, stoniness, silting, saltiness, and susceptibility to overflow, there may be differences of significance to the use of the soil for crops. The separation of phases then depends upon the purpose of the classification or mapping, the scale of mapping, the complexity of the soil pattern, and the type of farming. No soil type could, of course, have a very wide range in all of these. That is, some soils never have an excess of salts, and those that do would have suffered little or no accelerated erosion.

Slope may be taken as an example. There are generally recognized 5 classes of soil slope, usually designated as (A) level, (B) undulating (or gentle slopes), (C) rolling (or slopes), (D) hilly (or hills), and (E) steep. The slope of many soil types falls entirely within one of these classes; that of others may fall into two classes; and a few have slopes in more than two classes. Since the purpose of detailed soil mapping is to indicate those differences of significance to agriculture, these classes are defined in terms of their significance to land-use and their precise limits in terms of percentage will, of course, vary with different types of soils.[2] That is, with

[2] The broad definitions of classes of soil slope are as follows:

A. Nearly level or level soil on which external drainage is poor or slow. From the point of view of slope, there is no difficulty in the use of agricultural machinery nor is there likelihood of water erosion. The slope included within this class seldom exceeds 3 percent and for many soil types is less than 2 percent.

B. Gently undulating soil on which external drainage is good but not excessive. All types of ordinary agricultural machinery may be used without difficulty insofar as slope is concerned, and usually there is little likelihood of serious accelerated water erosion, or erosion can be controlled with relative ease through proper land management involving simple practices only. No definite upper limit of slope can be given that could be applied to all soils, but it is recognized that on many soil types this upper limit is about 5 to 7½ percent.

C. Gently rolling or rolling soils on which external drainage is good or free but not excessive. Practically all kinds of farm machinery can be successfully used except some highly specialized heavy types insofar as slope is concerned. The degree of susceptibility to erosion of these lands is extremely variable and depends upon the other characteristics of the soil. In general, tilled crops may be grown in moderately long to long rotations, although care is necessary in choosing and planting the crops, and in planning the rotation on certain soils. Proper tillage and fertilization practices are required. Definite measures for erosion control are necessary for many soil types within this slope class.

D. Strongly rolling to hilly soil on which the use of the more modern types of farm machinery is generally impracticable or very difficult. Run-off of water is rapid, but where soils are suitable, good permanent pasture may be maintained. In general, row field crops should not be grown, and close-grow-

soil types having a range in slope including both B and C classes, the line between them may fall at 5 percent, while for some others the critical change may fall at 6 percent, or even at 7 or 8 percent. As with any other soil characteristic, the significance of a variation in slope depends upon the other characteristics.

The same principle applies for other phases; general classes are defined in terms of agricultural significance and the precise definitions in mathematical terms are made for each soil type. The influence of a given loss of soil through erosion, for example, depends upon the character of the soil left. If the loss of 12 inches of surface soil exposes a hardpan, the use of the soil may be ruined. On the other hand the loss of even 24 inches may be much less serious, if the erosion is stabilized at that point and not allowed to continue, provided the lower horizons are soft and friable and do not contain injurious salts. The degree of detail with which erosion phases are defined depends upon the use of the maps and the seriousness of the erosion problem. Of course, if erosion has changed the soil to the extent that it has lost some of its important characteristics, it can no longer be classified as the same soil. That is, if all the deep dark A horizon of a Prairie soil or Chernozem has been removed by erosion (or in any other way), the soil can no longer be classified as a type within those groups.[8] Many soils are not subject to significant erosion.

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ing crops grown only in long rotation with grass or permanent pasture. Areas unsuited to grass because of unfavorable soil or moisture conditions should be used for forestry in humid regions.

E. Steeply sloping or very hilly soils adapted neither to cultivated crops nor to close-growing crops. Such land should not be plowed but, except under very favorable conditions for grass, should be maintained in forest wherever trees can grow. A sixth or F class of slope as a subdivision of E is sometimes used to include very steep or precipitous lands which are adapted to no agricultural use except in unusual situations where trees can maintain themselves. Such lands, however, are generally included in miscellaneous land types such as rough mountainous land or rock cliffs, which designate strictly nonarable land.

[8] The following definitions apply for detailed soil maps published on a scale of about 1 to 2 inches to the mile:

Eroded phase—Soils that have suffered recognizable erosion sufficient to affect materially the features of the surface soil, particularly its thickness, and to reduce significantly the productivity for the plants commonly grown on the

The soil complex is any association of soils composed of such an intimate mixture of areas of soil series, types, or phases, that these cannot be shown separately upon soil maps, and must be mapped as a unit. Each complex is defined according to the soil types and phases in it, their relative proportions, and their pattern. For example, small bodies of (1) soil developed from woody peat (Rifle peat), (2) poorly-drained dark-colored soil from sands (Newton loamy sand), (3) imperfectly-drained strongly podzolized soil from sand (Saugatuck sand), and (4) well-drained slightly podzolized soil from sand (Rubicon sand), may be so intimately associated that the whole group must be mapped as "Rifle-Rubicon complex." Similarly, mixtures of Griffin loam and Genesee loam may be mapped as a complex of "Griffin-Genesee loams."

The reader can best understand the classification and mapping of soils by looking at some recent soil map and the accompanying report, preferably in the field where he can see the soils themselves at the same time.[4] Several comparatively recent ones are listed. A great many new ones, some of which are even more accurate, are in the process of publication. Over 1400 others have been printed, beginning in 1899, but

uneroded soil. The productivity of the soil has been reduced by erosion, but erosion alone has not led to abandonment of the land. To secure normal production for the soil type, some differences in land management will be required, as compared to the normal soil type. In areas so eroded, small severely eroded spots may be common and conspicuous due to exposure of the subsoil.

Severely eroded phase—Soils that have been so eroded that the surface layers, ordinarily known collectively as the A horizon, have been largely lost. Ordinary plowing of such land will expose or turn up subsoil. Practically all soil types so eroded have had their productivity materially reduced. To secure normal production for the soil type definite differences in land management will be required. Gullies are significant features of soils subject to gullying (gullies of sufficient depth and length to require change of land use are indicated by gully symbols except as they are so extensive and numerous as to dominate the landscape). Subdivisions of this class may be essential in detailed mapping; for example, a *gullied phase* may be recognized.

Gullied land—Soil eroded to such an extent that use for ordinary agriculture is not feasible. Gullies are numerous and entrenched deeply into the subsoil or parent material; inter-gully areas have lost all or much of their surface soil. The soil profile over half or more of such areas is truncated to the extent of losing its differentiating characteristics and the separation is reduced to a miscellaneous land type: *Gullied land.*

[4] Before taking a soil map in the field for extended use it should be mounted on cloth to avoid tearing.

many of the early ones will require considerable interpretation to understand clearly, especially in terms of the currently accepted nomenclature. Most of these surveys in the United States have been made jointly by the U.S. Department of Agriculture and the State Agricultural Experiment Stations, and are available in the more important libraries. The form and content of the publications vary somewhat from place to place because of differences in soils, in agricultural problems, and in the intensity of the studies. Lists of available soil maps may be had from the U.S. Department of Agriculture.[5]

The following surveys have been selected as illustrative of particular soil regions. Those marked with an asterisk * contain a table of soil productivity ratings, one of the most important and useful features of modern soil surveys. Most of the others have a less precise grouping according to suitability for crops. To such a reference list should be added surveys of areas with which the reader is personally acquainted, even though the research might have been done several years ago. Then too, many new ones are published each year.

Surveys are listed under the predominating great soil group represented. Some represent several great soil groups and these are listed at the end under "composite." Each survey includes some commonly associated zonal and intrazonal soils and a few are listed that are especially illustrative of certain intrazonal soils.

Podzol soils

*Cheboygan County, Michigan 1934 [6] (Also Bog soils)
Kanabec County, Minnesota 1933

Brown Podzolic soils

Grafton County, New Hampshire 1935

[5] Except for Illinois where soil surveys are made and published by the State Agricultural Experiment Station at Urbana.

[6] For the sake of brevity only the name of the area and the series date are given. The complete reference would be as follows:

Soil Survey of Cheboygan County, Michigan. Z. C. Foster, A. E. Shearin, C. E. Millar, J. O. Veatch, and R. L. Donahue. *U.S. Dept. of Agr., Bur. Chem. and Soils, Soil Survey series 1934, Rept. 15. 1939.*

For the most recent surveys *Bur. Plant. Indus.* is substituted for *Bur. Chem. and Soils.*

Gray-Brown Podzolic soils
*Crawford County, Wisconsin 1930
Washington County, Indiana 1932 (Also Planosols)
*Clinton County, Michigan 1936 (In press)
*Otsego County, New York 1934
Logan County, Ohio 1933

Red Podzolic and Yellow Podzolic soils
*Jefferson County, Tennessee 1935
*Hall County, Georgia 1937 (Also some Rendzina)
*Sumter County, Alabama 1935 (Also Rendzina)
*Edgefield County, South Carolina 1935
Marion County, Mississippi 1934

Prairie soils
*Davis County, Iowa 1933
*Audubon County, Iowa 1933
*Cass County, Nebraska 1933

Reddish-Prairie soils
*Garfield County, Oklahoma 1935

Chernozem soils
*Brown County, Nebraska 1933
Cass County, North Dakota 1924

Reddish-Chestnut soils
*Woodward County, Oklahoma 1932

Chestnut soils
*McKenzie County, North Dakota 1933
*Frontier County, Nebraska 1935 (Also Chernozem)
*Hayes County, Nebraska 1934

Brown soils
Longmont Area, Colorado 1930

Reddish-Brown soils
Zavalla County, Texas 1934

Sierozem (or Gray-Desert) soils
*The Price Area, Utah 1934

Red Desert soils
Yuma Desert Area 1938
Casa Grande Area 1936

Planosols

*Allen County, Kansas 1935
Jennings County, Indiana 1932

Rendzina soils

*Kaufman County, Texas 1936

Bog soils

Saginaw County, Michigan 1933

Composite

Red River Valley Area, Minnesota 1933 (Reconnaissance survey of eight counties)
(Chernozem and Podzol)
*Bonner County, Idaho 1934
(Prairie, Brown Podzolic, Solonetz, etc.)
Sheridan County, Wyoming 1932
(Sierozem, Chestnut, Chernozem, Podzol, Solonetz, etc.)
*Puerto Rico 1936 (In press)
(Laterite, Red Podzolic, Rendzina, and many others)
The Napa Area, California 1933
(Chernozem, Solonetz, podzolic soils, etc.)

APPENDIX II

DESCRIPTIVE OUTLINE OF THE GREAT SOIL GROUPS

The great soil groups are the principal units in the broad classification of soils. In turn, these may be placed into further groups according to their most important characteristics. Finally, at the top of the scale, there are three orders —zonal, intrazonal, and azonal—determined wholly on the geographic features of the soils. In the following outline the great soil groups are arranged in their relationship to one another. Following this outline the principal features of each of the great soil groups and of the landscapes with which they are associated are set forth briefly in tabular form.

I. *Zonal soils.* These are soils with well-developed soil characteristics that reflect the dominating influence of climate and vegetation. They are found on all parent materials, not of extreme texture or chemical composition, on the gently undulating to rolling uplands, with good drainage, where there has been time enough for the biological forces to exert their full effect. Each zonal great soil group dominates the soils over a large area having certain climatic conditions and vegetation. When shown on maps, these regions are called zonal soil regions and each includes one or more families of a zonal soil group and its intrazonal and azonal associates. On mountains, they are distributed regularly on the slopes (vertical zonality) in a manner parallel to their horizontal patterns over smooth continental regions.

A. Soils of the cold zone
  1. *Tundra soils*

B. Light-colored soils of arid regions
  2. *Desert soils*
  3. *Red Desert soils*
  4. *Sierozem soils* (= *Gray Desert soils*)
  5. *Brown soils*
  6. *Reddish-Brown soils*

C. Medium dark-colored soils of semiarid grasslands
  7. *Chestnut soils*
  8. *Reddish-Chestnut soils*

D. Dark-colored soils of the subhumid to humid grasslands
   9. *Chernozem soils*
   10. *Prairie soils*
   11. *Reddish-Prairie soils*

E. Soils of the forest-grassland transition
   12. *Degraded Chernozem soils*
   13. *Noncalcic-Brown soils*

F. Light-colored podzolized soils of the cool-temperate and temperate timbered regions
   14. *Podzol soils*
   15. *Brown Podzolic soils*
   16. *Gray-Brown Podzolic soils*

G. Light-colored, podzolic, and lateritic soils of the warm-temperate and tropical forested regions
   17. *Yellow Podzolic soils*[1]
   18. *Red Podzolic soils*
   19. *Yellowish-Brown Lateritic soils*
   20. *Reddish-Brown Lateritic soils*
   21. *Laterite soils*

H. Red lateritic soils of warm-temperate to tropical, lightly forested regions with Mediterranean climate
   22. *Terra Rossa*[1]

II. *Intrazonal soils.* These are soils with more or less well-developed soil characteristics that reflect the dominating influence of some local factor of relief or parent material over the normal influence of climate and vegetation. Each group is found within two or more zonal soil regions, usually in small areas, although sometimes the special condition responsible for their formation may influence a large area.

A. Halomorphic soils (soils with characteristics due to an excess of soluble salts now or at some previous time during their formation, found in imperfectly drained areas having a subhumid to arid climate, or influenced by seawater).
   1. *Solonchak soils*
   2. *Solonetz soils*
   3. *Soloth soils*

B. Hydromorphic soils (soils with characteristics due to an excess of moisture all or part of the time, found in areas of restricted drainage).

B_1. Poorly drained
   4. *Bog soils*

[1] From some points of view at least, these are intrazonal soils.

5. *Half-Bog soils*
6. *Wiesenböden* (= *Meadow soils*)

B_2. Imperfectly drained

7. *Alpine Meadow soils*
8. *Ground-Water Podzol soils*
9. *Ground-Water Laterite soils*
10. *Planosols*

C. Calomorphic soils (soils with characteristics due to an excess of available calcium in soft parent materials, such as marl or soft limestone).

11. *Rendzina soils*
12. *Brown Forest soils*

III. *Azonal soils.* These are soils without well-developed soil profiles because of extreme youth, steep relief, or very sandy parent material. They are found within any of the zonal soil regions.

1. *Lithosols* (or skeletal soils)
2. *Alluvial soils*
3. *Dry Sands*

The locations of the zonal soil groups and some of the larger areas of intrazonal and azonal groups in the United States are shown on the map in Figure 21. Some of the most important characteristics of the soils and of the landscapes with which they are associated are summarized in the following table, beginning on page 330.

Characteristics of the Great Soil Groups and of the Landscapes with Which They Are Associated.

I. Zonal soils

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Tundra	Dark-brown peaty layers over grayish horizons, mottled with rust-brown. The lower substrata are ever-frozen.	Mosses, lichens, and low shrubs.	Cold; humid.	Gleization with mechanical mixing.	Fair to good for a few short-season crops.	Pasture and the production of a few short-season crops for subsistence. Hunting and trapping are also important to the sparse population.	Large areas in northern Alaska, associated with much Lithosol and Bog soil.
Desert	Light-gray or brownish-gray soil, low in organic matter, closely underlain by calcareous material. May have deep hardpan. Most of these soils have poorly developed soil profiles.	Scattered shrub-by desert plants, or nearly barren.	Temperate to cool; arid.	Calcification.	Medium to high, if irrigated.	Either grazing in very large units or by nomads, or intensively cultivated in small individual units, or by corporations in large units, where irrigated. Crops or fruit locally specialized.	Large areas in the region between the Cascade and Sierra Nevada Mountains and the Rocky Mountains.
Red Desert	Light reddish-brown surface soil with brownish-red or red subsoil, sometimes higher in clay content, closely underlain by calcareous material. May have a deep hardpan.	Scattered desert plants, mostly shrubs and cacti.	Warm-temperate to hot; arid.	Calcification and slight laterization.	Medium to very high, if irrigated.	Some native gardening in favored places, but mostly either grazing in very large units or by nomads, or intensively cultivated in small individual units, or by corporations in large units, where irrigated. Crops or fruit locally specialized.	Large areas in southern portion of southwestern United States.
Sierozem	Light-gray or brownish-gray soil grading into calcareous material at 1 to 2 feet. May have a deep hardpan.	Low desert shrubs with scattered grasses.	Temperate to cool; arid.	Calcificaton.	Medium to high, if irrigated.	Mostly grazing in large units or by nomads. A little wheat grown with uncertain dry-farming in large units where summer temperatures are low. Intensively cultivated in relatively small units, or by corporations in large units, where irrigated. The crops or fruits are usually specialized locally.	Large areas in central and northern intermountain regions and between Rocky Mountains and Cascade Mountains and in California.

Great Soil Group	The Soil Profile	Native Vegetation	Climate	Process of Soil Development	Productivity (for crop plants)	Present Use of Dominant Types in the Group	Notes on Occurrence in United States
Brown	Brown soil, grading through light-brown prismatic soil into a gray calcareous layer at 1 to 3 feet.	Short-grass and bunch-grass with some low shrubs.	Temperate to cool; semiarid to arid.	Calcification.	Low without irrigation, high if irrigated.	Grain growing in large units with uncertain dry-farming, and grazing in large units. Small, intensively cultivated farms with specialty crops if irrigated. Some dry farms with local irrigation.	Large areas in western central and northern Great Plains and small areas in the intermountain regions.
Reddish-Brown	Reddish-brown soil grading into a more red and somewhat heavier subsoil, and then into soft or hardened calcareous material.	Bunch grass and desert shrubs.	Warm-temperate to hot; semiarid to arid.	Calcification and slight laterization.	Medium to very high if irrigated.	Some native gardening and dry farming in favored places. Mostly grazing in large units or by nomads, or intense cultivation in small individual units, or by corporations in large units, where irrigated.	Some areas in southwestern United States on the moist side of the Red Desert.
Chestnut	Dark-brown friable and platy soil over brown prismatic soil, with a layer of lime accumulation at 1½ to 4½ feet.	Mixed tall and short grasses.	Temperate to cool; semiarid.	Calcification.	Medium; medium to high if irrigated.	Cereal grains, especially wheat, grown on relatively large farms under dry-farming. Some other crops grown, especially with supplemental, local irrigation. Excellent grazing in large units also. Some intense cultivation in small units also.	Large areas in central part of northern and central Great Plains. Small areas in intermountain regions.
Reddish-Chestnut	Dark reddish-brown surface soil with heavier and more reddish soil beneath, grading into a soft or hardened layer of lime accumulation at 2 feet or more.	Mixed grasses and shrubs.	Warm-temperate to hot; semiarid.	Calcification and slight laterization.	Medium; medium to very high if irrigated.	Cereal grains, especially wheat and grain sorghums, and cotton are grown on medium to large farms. Supplemental irrigation on local farms often used. There is also grazing in large units. Some intense cultivation of special crops in small individual units, or by corporations in large units, under irrigation.	Important areas in the southern Great Plains and in Puerto Rico.

Characteristics of the Great Soil Groups and of the Landscapes with Which They Are Associated (*continued*).

I. Zonal soils

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Chernozem	Black or very dark grayish-brown friable soil, high in humus, to a depth of 1½ to 3 feet, grading through lighter colored soil to a light gray layer of lime accumulation.	Tall and mixed grasses.	Temperate to cool-temperate; subhumid.	Calcification.	Medium to high; high to very high when irrigated.	Cereal grains, especially wheat, in medium to large units. Corn, sugar beets, and some other crops grown also, especially with supplemental irrigation. The most important soils in the world for bread grains.	Large areas in eastern part of northern and central Great Plains; in northeastern Kansas, eastern Nebraska, South Dakota and North Dakota and western Minnesota. Small areas in intermountain regions.
Prairie	Very dark-brown or grayish-brown soil, grading through slightly heavier brown soil to lighter colored parent material at 2 to 5 feet. Slightly to medium acid in the solum.	Tall grasses.	Temperate to cool; humid (to subhumid).	Calcification with slight podzolization.	High to very high.	Medium-small to medium-large farm units. General farming, with emphasis on corn, hogs, and cattle. Among the most productive soils in the world for animal fats.	Large area in the Middle West, including nearly all of Iowa and parts of Minnesota, Wisconsin, Illinois and Missouri, with scattered areas elsewhere.
Reddish-Prairie	Dark-brown or reddish-brown soil grading through a somewhat heavier, reddish-brown subsoil to the parent material at 2 to 5 feet. Medium acid in the solum.	Tall and mixed grasses with occasional shrubs.	Warm-temperate (possibly to hot); humid to subhumid.	Calcification with slight laterization and podzolization.	Medium to high; high to very high when irrigated.	Small to medium large farm units with general farming, including wheat, oats, corn, cotton, and hay and other forage crops.	Relatively small areas in central Oklahoma and north-central Texas.
Degraded Chernozem	Nearly black A_1 horizon underlain by gray, leached A_2 horizon over dark-brown heavier B_2 horizon. Beneath, are the remnants of a layer of lime accumulation, but the solum is medium to strongly acid.	Forest vegetation, usually somewhat stunted, along with some tall grasses.	Temperate to cool; humid to subhumid.	Calcification followed by podzolization.	Ordinarily, medium to high, but low where strongly degraded.	Intermediate between Chernozem and Podzol.	Only a few very small areas in northwestern Minnesota, and on mountain slopes just above Chernozem. Not important in United States.

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Noncalcic-Brown	Light pinkish or light reddish-brown slightly acid surface soil, over reddish-brown heavier prismatic subsoils.	Thin, deciduous and coniferous forest, with brush and grass.	Temperate to warm-temperate; wet-dry, subhumid to semiarid.	Calcification (and weak podzolization?)	Medium; medium to high when irrigated.	Grain grown in medium-large units or grazing in large units. Special crops and fruits grow in small individual units, or by corporations in large units, when irrigated.	Small areas in southern and central California and in southern and central Arizona.
Podzol	A few inches of leaf mat and acid humus, a very thin dark gray A_1 horizon, a light-gray A_2 a few inches thick, a dark-brown B_2 horizon, and sometimes a yellowish-brown B_3 horizon over the lighter-colored parent material at 15 to 30 inches. Strongly acid.	Coniferous, or mixed deciduous and coniferous forest. (May have some heath vegetation.)	Cool-temperate, humid.	Podzolization.	Usually low; medium with good management.	Small farms with a high degree of subsistence and emphasis on dairying. Some specialization with potatoes. Wood lots and pasture important. Large areas in forest.	Large areas in the northern Lake States and northern New England. Small areas near north Atlantic seaboard and on mountains. (Many of these soils in the United States are stony.)
Brown Podzolic	Leaf mat and acid humus over thin dark-gray A_1 horizon, and thin grayish-brown or yellowish-brown A_2 over slightly heavier brown B horizon. Solum about 18 to 30 inches thick. Medium to strongly acid in solum.	Deciduous, or mixed deciduous and coniferous forest.	Cool-temperate to temperate; humid.	Podzolization.	Low to medium-low; medium to high with good management.	Small farms with a high degree of subsistence and emphasis on dairying, truck crops, and fruit. Woodlots and pasture important.	Mostly in southern New England with small areas elsewhere near southern margin of Podzol soil region. (Most of these soils in New England are stony.)
Gray-Brown Podzolic	Thin leaf litter over mild humus, very dark gray A_1 horizon 2 to 4 inches thick, grayish-brown leached A_2 horizon 5 to 12 inches thick, brown heavier B horizon. The lighter colored parent material at about 30 to 50 inches. Medium to strongly acid in solum.	Mostly deciduous forest with some conifers in a few places.	Temperate; humid.	Podzolization.	Medium; medium to very high with good management.	Small or medium units with general arming. These soils are adapted to a very wide range of crops, including grains, pasture, and forage for livestock, fruits, and vegetables. There is some specialization. (Much industrial activity.)	Large areas between the Mississippi River and the Atlantic Ocean, from central Michigan, to southern Kentucky. Also other small areas in humid, temperate parts of the Northwest and intermountain regions.

Characteristics of the Great Soil Groups and of the Landscapes with Which They Are Associated (*continued*)

I. Zonal soils

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Yellow Podzolic	Thin dark-colored organic covering over pale yellowish-gray leached layer, 6 to 36 inches thick over heavy, yellow B horizon. The yellow, red, and gray mottled parent material lies at 4 to 6 feet beneath the surface. Strongly acid in solum.	Coniferous or mixed deciduous and coniferous forest.	Warm-temperate to tropical; humid.	Podzolization with some laterization.	Low; medium to high with good management.	Mostly very small to medium-sized farms but with some large units. Much specialization in cotton, tobacco, and peanuts, along with vegetables, fruit and subsistence crops. But few livestock. Many wood lots and forested areas for lumber, turpentine, and paper pulp.	Large areas throughout southeastern United States from Norfolk, Virginia to east-central Texas, especially in the Coastal Plain, and in other very gently undulating areas. Also found in Puerto Rico.
Red Podzolic	Thin organic layer over yellowish-brown or grayish-brown leached surface soil over deep-red B horizon. The parent material, frequently mottled with red, yellow, and gray, is about 4 to 8 feet beneath the surface. Medium to strongly acid.	Deciduous forest with some conifers. (Burned areas sometimes covered with tall coarse grasses.)	Warm temperate to tropical; humid.	Podzolization and laterization.	Low to medium; medium to very high under good management.	Mostly very small to medium-sized farm units with some large plantations. Much specialization in cotton and peanuts, and some in fruits and nuts. Corn, tobacco, vegetables, and many subsistence crops grown, and some livestock. Much waste land and many forested areas. Erosion has been especially serious.	Large areas throughout southeastern United States, especially in the Piedmont region and other gently rolling areas. Also found in Puerto Rico.
Yellowish-Brown Lateritic	Brown, friable clay loams and clays over yellowish-brown heavy, but friable clays. Neutral to strongly acid.	Evergreen and deciduous forests; tropical rain forests.	Tropical; humid to wet (sometimes with dry seasons).	Laterization and some podzolization.	Low; medium to high with irrigation and fertilization.	Mostly small farm units (or large gardens) with subsistence and some special crops. Some large plantations. Portions in forest.	None in continental United States. Small areas in Puerto Rico and Canal Zone and at the higher elevations in Hawaii.
Reddish-Brown Lateritic	Reddish-brown or dark reddish-brown friable or porous clayey soil over deep-red friable and porous clay. May be mottled in deep substratum. Neutral to strongly acid.	Tropical rain forest to margin of savannah.	Tropical; humid to wet (som - times with dry seasons).	Laterization (with slight or no podzolization).	Low to medium; medium to very high where fertilized, and irrigated if necessary.	Small farm units (or large gardens) with subsistence and some special crops. Many plantations with specialization in sugar cane, pineapples, citrus, etc. Some forests.	None in continental United States. Small areas in Puerto Rico and Canal Zone, and much in Hawaii.

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Laterite	Brownish-red surface soil over red porous clay. Red or mottled parent material, usually very deeply weathered.	Tropical rain forest and savannah.	Tropical; humid to wet (sometimes with dry seasons).	Laterization, and a little podzolization.	Low; medium to high with heavy fertilization, and irrigation when needed.	Small farm units (or gardens) with subsistence and some special crops. Some plantations with specialization in sugar cane, rubber, etc. Large areas of waste land and forest.	None in continental United States. Small areas in Puerto Rico and Canal Zone.
Terra Rossa	Reddish-brown calcareous, friable clay loams over material weathered from hard limestone or marble at depths from a few inches to many feet.	Relatively thin forest of conifers and deciduous trees with some shrubs and grass.	Warm-temperate to tropical; Mediterranean (wet-dry) climate.	Laterization; calcification. (?)	Low to medium; medium to high with good management.	Small farm units with emphasis upon grapes and olives, together with other fruits, vegetables and some grain and pasture, especially for sheep and goats.	None in United States.

II. Intrazonal soils

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Local Factors Responsible for Development*	*Drainage*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Solonchak	Gray, thin salty crust on surface, fine granular soil just below, underlain by grayish friable salty soil. Many variations. Interior Solonchaks have salts concentrated in layer beneath the surface. Mildly to strongly alkaline.	Sparse growth of salt-loving grasses, shrubs, and some trees.	Cool to hot; usually arid to subhumid, but some in humid areas near the sea.	Poor drainage and evaporation of water, leaving salts behind, or other processes leading to a concentration of salts.	Poor or imperfect.	Salinization	Very low unless drained and salts removed.	Some meagre grazing. Much is essentially waste land.	Many scattered areas throughout subhumid, semiarid, and arid regions, usually too small to show on small-scale maps. Many areas have been formed as a result of irrigation, especially of adjacent higher land.

Characteristics of the Great Soil Groups and of the Landscapes with Which They Are Associated (*continued*).

II. Intrazonal soils

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Local Factors Responsible for Development*	*Drainage*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Solonetz	Very thin friable surface soil underlain by dark, columnar horizon of hard clay, usually highly alkaline. There are many variations and many transitions to Solonchak and Soloth. Where there is a significant light gray A_2 horizon above the columnar clay, the soil is called a solodized-Solonetz. Usually has a layer of lime accumulation just beneath the B horizon or partly in the lower portion of it.	Salt-loving plants and thin stands of vegetation native to the adjacent soils.	Cool to hot; usually semiarid to subhumid.	Improved drainage and partial leaching of a Solonchak containing much sodium salts, like sodium chloride or sodium sulphate.	Imperfect.	Solonization (Removal of sodium salts and development of highly alkaline reaction.)	Very low or low; medium where reclaimed by drainage and use of sulphur or calcium sulphate as amendments.	Poor to fair grazing. Much is essentially wasteland. Where reclaimed used as associated normal soils.	Many scattered areas throughout subhumid and semiarid regions and some in arid regions. Frequently, occurs as very small spots ("slick" or "scabby" spots) in other soils, especially the solodized-Solonetz. Some areas caused by irrigation of a sodium-Solonchak.
Soloth	Thin grayish-brown horizon of friable soil over light-gray leached A_2 horizon underlain by dark-brown heavier horizon. Usually has a layer of lime accumulation just underneath the B horizon. Mildly to strongly acid in the solum.	Mixed grasses with some trees or shrubs in places.	Cool to hot; subhumid to semiarid.	Improved drainage and leaching of a Solonetz.	Imperfect to good.	Solodization.	Low to medium.	Used much the same as associated normal soils.	Only a few areas in region of Chernozem soils or near the boundaries of Chernozem and Prairie soil regions.

Great Soil Group	The Soil Profile	Native Vegetation	Climate	Local Factors Responsible for Development	Drainage	Process of Soil Development	Productivity (for crop plants)	Present Use of Dominant Types in the Group	Notes on Occurrence in United States
Bog	Brown, dark-brown, or black peat or muck over brown peaty material. May be strongly acid to slightly alkaline.	Swamp forest or sedges and grasses.	Cool to tropical; generally humid.	Poor drainage; water table at or very near the surface most of the time.	Very poor.	Gleization (and peat formation).	Very low (except for a few very special crops like cranberries); some types are medium to high where drained and fertilized.	Much is in swamp forest or marsh. Especially those fairly well decomposed in the surface and not too acid are used for special crops where drained and fertilized. Some used for pasture.	Many areas in Podzol region but too cold for much use for crops. Large areas used in Gray-Brown Podzolic region. Several large areas in Coastal Plain, and in the Pacific coast region. Most areas are too small to be shown on small-scale maps.
Half-Bog	Dark-brown or black peaty material over grayish and rust-mottled mineral soil. May be strongly acid to slightly alkaline.	Swamp forests mostly, but some with sedges.	Cool to tropical; generally humid.	Poor drainage; water table very near the surface a large part of the time.	Very poor.	Gleization.	Very low or low; some types are medium to very high where drained and well managed.	Used for forest or pasture where undrained. Some of the better types are used for same general crops as associated normal soils or for special crops. Those acid and underlain by sand not much used. Many of those neutral and underlain by sandy clay or clay are used intensively.	Many areas, especially associated with Podzol, Gray-Brown Podzolic, and Yellow Podzolic soils. Large areas in old lake plains near the Great Lakes are very productive when drained.
Wiesenböden (Meadow soils)	Dark-brown or black soil, high in humus, grading at 1 to 2 feet into grayish and rust-mottled soil. Mostly slightly acid to slightly alkaline.	Grasses and sedges.	Cool to warm; humid to subhumid.	Poor drainage.	Poor.	Gleization and calcification.	Low; medium to very high when drained.	Better types used for general crops as associated normal soils or for special crops. Most of these soils are neutral and very productive when drained. Their use is much like that of the Prairie soils which they resemble after drainage.	Many areas in association with the Prairie soils, as in poorly drained parts of Iowa and northern and central Illinois. Also found in other regions of podzolic soils and associated with Chernozem

Characteristics of the Great Soil Groups and of the Landscapes with Which They Are Associated (*continued*).

II. Intrazonal soils

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Local Factors Responsible for Development*	*Drainage*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Alpine Meadow	Dark-brown friable soil grading, at a depth of 1 to 2 feet, into friable, yellowish and grayish soil streaked and mottled with yellowish-brown.	Alpine flowering plants, grasses, and sedges.	Cool-temperate to frigid (Alpine).	Cold climate and poor drainage.	Imperfect or poor.	Gleization and some calcification.	Medium for pasture. Too cold for crops.	Use for summer grazing in the high mountains.	Scattered areas above the timber line in the high mountains like the Cascades and the Rockies.
Ground-Water Podzol	Mat of raw organic matter over very thin dark-gray A_1 horizon, over light gray leached A_2 horizon 6 to 36 inches thick, over brown or very dark-brown cemented B_2 horizon (ortstein). The parent material is reached at 2 to 5 feet below the surface and is usually gray or grayish-yellow. Strongly acid.	Forests of various types, but usually coniferous. May have some heath vegetation.	Cool to tropical; humid.	Imperfect drainage on very sandy material low in lime.	Imperfect; the water table usually fluctuates from the top to the bottom of the B horizon.	Podzolization.	Low to medium in cool regions; low in warm regions.	Mostly in forest. Some areas, especially in the cool-temperate regions, used for common crops and pasture grasses.	Small scattered areas in Podzol and northern part of Gray-Brown Podzolic soil regions. Large areas on nearly flat, very sandy Coastal Plain, especially in Florida.
Ground-Water Laterite	Gray or grayish-brown surface layer, over leached yellowish-gray A_2 horizon, over thick, reticulately mottled and cemented hardpan, one to several feet in thickness. Parent material of the type originally called laterite. Concretions throughout. Acid.	Tropical forest.	Warm to hot; humid (usually with dry seasons).	Imperfect to poor drainage and great age.	Imperfect to poor.	Intense laterization, and podzolization.	Very low to medium.	Mostly forest or waste land. Some used for subsistence crops, sugarcane, rice, etc.	None in United States.

Great Soil Group	*The Soil Profile*	*Native Vegetation*	*Climate*	*Local Factors Responsible for Development*	*Drainage*	*Process of Soil Development*	*Productivity (for crop plants)*	*Present Use of Dominant Types in the Group*	*Notes on Occurrence in United States*
Rendzina	Dark-gray to black heavy granular soil underlain by gray or yellowish soft calcareous material, especially marl or very soft limestone. Neutral to slightly alkaline.	Mostly grasses.	Cool to hot; humid to semiarid (usually humid).	High content of calcium carbonate available to plants in soft parent material.	Imperfect to poor.	Calcification.	Medium to high.	Used mostly for crops grown on associated normal soils, but may have some specialization.	Areas of rather poorly developed Rendzina in "Black Belt" of Alabama and Mississippi. Large area of excellent Rendzina in east-central Texas. Scattered areas elsewhere, including Puerto Rico.
Brown Forest	Neutral, granular surface organic layer over dark-brown granular surface soil, high in humus, grading through lighter-colored soil to parent material at 2 to 4 feet; very little texture profile.	Forest, mostly deciduous.	Cool, temperate to warm-temperate; humid.	High content of available calcium in parent material, and youth.	Good.	Calcification with little or no podzolization.	For the better types medium to high; very high with good management.	Used about like the Gray-Brown Podzolic soils, but requires less liming and fertilization.	Only very small unimportant and scattered areas in United States. (Very important in western Europe.)
Planosol	Strongly leached surface soils over claypans, siltpans, or hardpans. A few have nearly normal A and B horizons above the claypan or hardpan.	Mostly forest, but much with grasses.	Cool-temperate to tropical; humid to subhumid.	Nearly flat relief on parent materials of medium to heavy texture; less than normal erosion; and imperfect drainage.	Imperfect; very wet during moist seasons.	Podzolization (and some gleization).	Low to medium. Can be raised by very careful management. Very seriously injured by accelerated erosion where it occurs.	Used for about the same crops as adjacent normal soils, although ordinarily not useful for fruit trees or some other perennial plants.	Small scattered areas on smooth relief in humid regions. Large areas in southern Illinois, southern Indiana, northern Missouri and eastern Kansas.

Characteristics of the Great Soil Groups and of the Landscapes with Which They Are Associated (*continued*).

III. Azonal soils

Great Soil Group	*The Profile*	*Native Vegetation*	*Climate*	*Drainage*	*Processes of Soil Development*	*Productivity and Present Use*	*Notes on Occurrence in United States*
Lithosols	Thin surface soils usually closely underlain by soft or hard rocks. Mostly very stony throughout; shallow.	Forest, shrubs, or grass, depending on climate. Many areas nearly barren.	All climates. Most common in the desert, and least so in wet tropical regions.	Mostly free to excessive. (Mostly, but not entirely steeply sloping.)		Mostly used for forestry and grazing. There are many barren areas. Very limited farming, or gardening, with subsistence crops.	Found on mountain slopes, extremely hilly areas, and where parent material for soil has not developed from the underlying rocks.
Alluvial Soils	Stratified deposits of alluvium with little or no modification except, perhaps, for a slight accumulation of organic matter in the surface. Additions of sediments to the top made from time to time.	Forests, shrubs, or grass, depending upon climate and drainage.	All climates, except extremely frigid.	Poor to good, but variable with seasons since these soils are mostly subject to periodic overflow. (Mostly nearly level.)	Those characteristic of the region, but not sufficient influence has been made to develop internal soil characteristics.	These soils vary from very low to very high in productivity. Used for crops grown on adjacent normal soils and for special crops. A large part of the world's population gets its food supply from these soils. In warm-temperate and tropical regions especially, there are many large plantations specializing in sugar cane, rubber, cotton, bananas, etc. Many small subsistence farms producing rice and other crops. In the United States these soils are widely used for corn, cotton, pasture and hay.	Large areas in the United States along the major streams like the Mississippi, the Ohio, the Platte, and many others, beside small narrow strips along the small streams, especially in the hill-valley parts of the humid region, and great areas in the semiarid and arid regions. Much of the irrigation in the United States is on Alluvial soils of these regions. Important in Puerto Rico.
Dry Sands	Loose sands with little or no profile except for a staining of the upper part with organic matter.	Scanty forest, shrubs, or grass. Many areas are essentially barren.	Temperate to hot; humid to arid.	Excessive.		Very seldom used except for grazing or forestry.	There are many areas throughout the country, especially in the deserts and along the margins of large lakes and the ocean. A large area in northwestern Nebraska is used for grazing in large units.

APPENDIX III

WHERE TO LOOK

A few suggestions for further reading are given for those readers who wish to dig a little deeper into some of the subjects mentioned. Of course, there is a large body of literature about soils and the relationship of soil science to agriculture, geography, land-use planning, nutrition, and similar fields. A few books are listed that contain additional information and guide the reader to other references, as well as a few of historical interest that show how modern ideas of the soil have developed.

Several departments and bureaus of the national government, and more especially the Department of Agriculture, as well as the state experimental stations, publish a great many pamphlets dealing with particular aspects of fundamental and applied soil science. Similar bulletins are published by experimental stations in other countries. Although these bulletins and circulars vary a great deal, many of them are excellent. If the reader is interested in some definite area of soil or some specific soil problem, such bulletins and the detailed soil survey (if one is available for the area), are frequently an excellent source of information. Attempts are made to keep the bulletins up to date, and those published by the state experimental stations are particularly directed toward local problems. These stations and the national bureaus publish lists from time to time of available bulletins from which selections can be made.

There are also several scientific journals devoted wholly or partly to the current findings of soil research. Some of the more important of these published in the United States, are as follows: *Soil Science,* Proceedings of the Soil Science Society of America,* Journal of the American Society of Agron-*

* Those marked with a single asterisk (*) are devoted almost entirely to articles dealing with soil; those marked with a double asterisk (**) devote about one-half of their attention to soil science; and those marked with a triple asterisk (***) have only occasional articles dealing with soil work.

*omy,*** *Journal of Agricultural Research,**** *Ecology,**** and *Annals of the Association of American Geographers.**** Of course, several of the farm magazines, and a few of those devoted to conservation and natural resources in general, print articles dealing with practical soil problems of current interest.

The modern trend toward specialization has made the problem of recommending books difficult. Many books dealing with soils are too specialized for the general reader, and he will need to tie the various specialities together for himself. Further, soil science, like any other subject, is incomplete by itself. To a great degree it is a science that deals with relationships. To be understood, one must also have some knowledge of literature, history, anthropology, geology, botany, chemistry, and the other arts and sciences. For example, books like Oswald Spengler's *Decline of the West,* Buckle's *History of Civilization in England,* Faure's *History of Art,* C. de Tocqueville's *Democracy in America,* Fraser's *Golden Bough,* Webb's *The Great Plains,* Tolstoy's *War and Peace,* Sackville-West's *The Land,* George Sand's *The Devil's Pool,* and many others are not out of place in a library in soil science if that science is to be related to others and contribute to our understanding of the trends of civilization and our future development. But in the list that follows only a few books dealing directly with soils or very closely related subjects are indicated.

Of the books listed, those preceded by the figure 1 in parentheses are easiest to read, and those with a 3 either require considerable familiarity with scientific terminology, or treat the subject in a highly detailed and specialized manner. Those marked (2) are intermediate but require some knowledge of science. Several are marked with two, or all three numbers, because different portions of the book fall into different classes from this point of view.

(1, 2) *Mother earth.* G. W. Robinson. Murby. 1937.
This is a delightful little book on soils by a well-known professor in Wales, intended for the general reader who already has some little knowledge of the agricultural sciences. It is a small

book with about 200 well-written pages and a few illustrations.

(1, 2, 3) *Soils and Men.* The Yearbook of Agriculture for 1938. U.S. Department of Agriculture.

This is a large book of over 1200 pages with many articles on different phases of fundamental soil science, applied soil science, and the relationship of soil science to other subjects, by a large staff of writers. The quality and technicality of the many articles in it vary a great deal, but so many things are discussed that almost anyone interested in any phase of soil science will find something useful. A rather comprehensive glossary of technical terms, a large generalized map, in color, of the soils of the United States, and many illustrations are included.

(2, 3) *Soil Conditions and Plant Growth.* Sir E. J. Russell. 7th edition. Longmans. 1937.

The director of the Rothamsted Experimental Station in England and his staff have prepared a standard reference work on the subject. Although rather technical in places and not extremely well organized, it is well written. It contains not only an enormous amount of valuable information, but also an excellent list of references to original papers and other books. In all, it has about 650 pages and many illustrations.

(2) *The Nature and Properties of Soils.* T. L. Lyon and H. O. Buckman. (3rd edition) Macmillan. 1937.

This book is used widely in the United States as a text for beginning courses in soil science, especially when given to students during their second year of college. It is intended as a text, to be supplemented by lectures to bring out local relationships and applications. There are about 400 pages with several excellent diagrams.

(3) *Soils, Their Origin, Constitution, and Classification.* G. W. Robinson. (2nd edition) Murby. 1936.

The purpose of this book is to serve as a general text or reference dealing with the processes of soil formation and the principles of classification. Particular attention is given to methods employed in Britain, although a lot of attention is also paid to work in the United States and other countries. There are nearly 450 pages.

(3) *Soils of the United States.* C. F. Marbut. Published in Atlas of American Agriculture, U.S. Department of Agriculture. 1935.

This work is published in large folio size (18¾″ × 13½″) with many maps in color, including a very large map of the United States, in addition to 98 pages of text. Most of the

maps were prepared before 1930 and the publication represents Dr. C. F. Marbut's personal interpretation of work in soil geography done in the United States up to that time. The chemical analyses of many soils are included. It is, however, somewhat too technical for the beginner.

(3) *Pedology*. J. S. Joffe. Rutgers. 1936.

The main feature of this book is its explanation and summary of the work done by the Russian soil scientists, who led the world for many years in the study of soil formation and classification. Some other examples from the United States and elsewhere are mentioned also. There are 575 pages, not too easy to read.

(2, 3) *Soils*. E. W. Hilgard. Macmillan. 1906.

The standard work on soils for many years in America was this text of nearly 600 pages written by one of the great pioneers. Hilgard was the first American scientist to see and appreciate the close relationship between soil character and native vegetation. Although soil science has advanced greatly in the 35 years since this book was written, it is still very valuable to the modern student.

(3) *The Great Soil Groups of the World and Their Development*. K. D. Glinka. (Translated from the German by Dr. C. F. Marbut.) Edwards Brothers. 1927.

The translation of Professor Glinka's lectures into German, and finally into English by Dr. Marbut, made available in western Europe and the United States especially, new facts and ideas developed by the great Russian school of soil science of which Professor Glinka was the distinguished leader for many years. The book had a tremendous influence upon the whole course of soil science, and especially of soil classification and geography in the United States. This translation consists of 150 pages, lithoprinted from typed sheets. There are many valuable tables of chemical analyses.

(2, 3) *Proceedings of the International Congresses of Soil Science*. 1st Washington, 1927, 4 volumes; 2nd Moscow, 1930, 7 volumes; 3rd, London, 1935, 3 volumes.

The volumes of these three large international conferences, lasting for many days and attended by people from all over the world, are a library of recent advanced soil science in themselves.

(1) *Husbandry*. L. I. M. Columella (written in Rome about A.D. 60), English translation, 1745.

This is probably the most famous book ever written on agriculture. The author explains many good practices of soil and crop management that are still good, although science has found the reasons and made it possible to apply them more precisely.

(1, 2) *Soil Surveys.* U.S. Department of Agriculture. 1899 to the present.

More than 1,700 soil maps and reports have been prepared by the Division of Soil Survey in cooperation with state research institutions, especially the state agricultural experiment stations. Lists are available in the Department of Agriculture that indicate the counties already surveyed, those where copies are available for distribution, and the libraries in each state that maintain complete sets of the maps and reports. In general, the accuracy and completeness of the maps and reports have increased steadily with the years, as knowledge about soils and their uses has increased.

For any particular area, these publications are the best source of specific information on soil geography. Many of the older surveys published before about 1917 are quite general, and it has been necessary to change some of the soil names. The addition in the recent reports of a table of productivity ratings for each soil type or phase shown on the soil map, for each adapted crop, marks another great advance. The U.S. Department of Agriculture has published a *Soil Survey Manual,* as Miscellaneous Publication No. 274 (136 pages), which explains the methods used.

For Illinois, surveys are published by the University at Urbana.

(1, 2, 3) Bulletins of the State Agricultural Experiment Stations and of the United States Department of Agriculture.

There are a great many of these published on various phases of soil science. Lists may be had from the institutions upon request.

APPENDIX IV

GLOSSARY

This glossary is intended to give definitions or explanations of some of the more technical words and phrases used in this book, as well as some in other books and papers on soils that may fall into the reader's hands. Since the definitions of the great soil groups, such as Chernozem and Solonetz, are given in Appendix II they will not be repeated here.[1]

A B C soil. A soil with a complete profile, including an A, a B, and a C horizon.

A C soil. A soil with an incomplete profile, including an A and a C, but no B horizon. These soils are usually very young, such as those developing from alluvium, from dry, nearly pure sand, or on steep, rocky slopes.

Acid soil. From a practical point of view, a soil that is acid throughout most or all of the portion occupied by plant roots. (Precisely, any soil horizon having a pH value less than 7.0, but in practice a soil with a pH value above 6.6 is not considered to be acid. See pH).

Agricultural land. Land in farms regularly used for agricultural production. The term includes all land used for growing crops and livestock.

Alkali soil. A soil containing strongly alkaline salts, usually sodium carbonate (Na_2CO_3). Locally the word is sometimes used very broadly and includes saline or salty soils that are not highly alkaline.

Alkaline soil. A soil that is alkaline throughout most or all of the portion occupied by plant roots. (Precisely, any soil horizon having a pH value greater than 7.0, but in practice a soil with pH value below 7.3 is not considered to be alkaline. See pH).

Alluvial soils. Soils developed from recently deposited alluvium, so young that there has been little or no change in the soil ma-

[1] Some words and phrases have been used by different writers in more than one sense, and especially in the older books and papers, the reader will need to be certain that the author has not used some term in a special way according to some old or local usage. Many of these explanations are based on a glossary prepared by the writer for *Soils and Men,* the Yearbook of Agriculture for 1938.

terial by processes of soil formation. (The Alluvial soils are an azonal group and *do not* include soils with well-developed profiles that have formed from alluvium).

Alluvium. Sand, mud, and other sediments deposited on the land by streams.

Ammonification in soils. The formation by soil organisms of ammonium compounds, especially from organic materials such as tree leaves, straw, or manure.

Arable land. Land that can produce crops requiring tillage without clearing or other physical improvements.

Arid climate. A very dry climate like that of desert or semi-desert regions where there is only enough water for widely-spaced desert plants.

Ash. The mineral matter left after the complete burning or decomposition of organic matter.

Association, soil. A group of soils that may or may not have similar characteristics, but which are found associated together in an individual pattern. In soil mapping, if the individual soils exist in such small areas that they cannot be shown separately on the map, the whole group is called a *soil complex.*

Azonal soils. Any group of soils without well-developed profiles. These are: Alluvial soils, Lithosols, and Dry Sands.

Badlands. Nearly barren, rough, broken land, deeply cut by streams. This land is most common in arid and semiarid regions where streams have cut deeply into soft rocks. The name comes from an early expression, "bad lands to ride over."

Basin Listing. A method of tillage by which small, rectangular basins are made by damming lister furrows at intervals of 4 to 20 feet. This method is a modification of ordinary listing and is done approximately on the contour on nearly level to gently sloping soils in the southern plains, especially on Reddish-Chestnut soils in western Kansas, southeastern Colorado, western Oklahoma, northwestern Texas and northeastern New Mexico, as a means of encouraging water to enter the soil rather than run off the surface.

B C soil. A soil with an incomplete profile (including a B and a C, but with little or no A horizon). Most B C soils have lost the A horizon by erosion. Sometimes these are called *truncated soils,* although a truncated soil may have lost all of both A and B.

Calcareous soil. Any soil containing enough calcium carbonate

to effervesce ("fizz") when treated with hydrochloric acid. Because of the calcium carbonate the soil is alkaline.

Calcification. A general term for those processes of soil formation in which the surface soil is kept supplied by the plants with enough calcium to prevent the soil from becoming acid and the colloids from leaching out. The process is best expressed by Chernozem and is in striking contrast to podzolization, best expressed in the Podzol.

Caliche. A more or less cemented deposit or layer of calcium carbonate found in many soils of warm-temperate, to hot, semiarid or desert regions, as in the Reddish-Chestnut and Reddish-Brown soils of southwestern United States.

Carbon-nitrogen ratio. The relative proportion, by weight, of organic carbon to nitrogen in a soil. Values range roughly from 4 to 15, but are approximately constant for any one mature soil.

Catena, soil. A group of soils within a specific soil zone developed from similar parent materials, but with different soil characteristics owing to differences in relief or drainage.

Clay. The small mineral soil particles less than 0.002 millimeters in diameter. (Formerly included particles less than 0.005 mm. in diameter).

Claypan. A dense and heavy soil horizon underlying the upper part of the soil, hard when dry and plastic when wet. This kind of horizon is the most prominent feature of many Planosols.

Colloid, soil. This term is used in reference to inorganic and organic matter having very small particle size. For a given weight of material, colloidal particles have an enormous surface area as compared to sand. Most of the individual soil colloid particles are too small to be seen with the ordinary compound microscope. Although colloids do not go into true solution like sugar or salt, they may be dispersed into a relatively stable suspension and move with the moving water. Or they may be flocculated or aggregated into small clumps or granules that are not suspended in water. Many mineral soil colloids are really tiny crystals that can be identified from their X-ray patterns.

Colluvium. Mixed deposits of rock fragments and soil material at the base of comparatively steep slopes, accumulated through slides, creep, and local wash.

Complex, soil. A soil association composed of such an intimate

mixture of areas of soil series, types, or phases that these cannot be shown separately on the soil map, and must be shown and described as a unit.

Concretions. Local concentrations of certain chemical compounds, such as calcium carbonate, or iron, that form hard grains, pellets, or nodules of mixed composition, frequently unlike that of the surrounding soil mass, and of various sizes, shapes, and coloring.

Consistence, soil. The relative mutual attraction of particles in the soil mass; or their resistance to separation (cohesion), or the ability of the mass to undergo a change in shape without rupture (plasticity). The consistence of the whole mass of soil, or of an individual aggregate of soil, may be described as loose, mellow, friable, crumbly, sticky, plastic, stiff, soft, firm, hard, compact, or cemented.

Degradation (of soils). Change of one soil type to a more highly leached one as, for example, the change of a Chernozem toward a Podzol.

Duff. A matted, peaty organic surface horizon of forested soils.

Edaphic. A general term for soil influences or conditions.

Eluviation. The movement of soil material from one place to another within the soil, in solution or in suspension, where there is an excess of rainfall over evaporation. Horizons that have lost material through eluviation are referred to as *eluvial* and those that have received material, as *illuvial.* Eluviation may take place downward or sidewise according to the direction of the water movement. This term refers especially, but not exclusively, to the movement of soil colloids, whereas leaching refers to the complete removal from the soil of material in true solution.

Erosion, land. The wearing away of the land surface by runing water, wind, or other geological agents, including such processes as creep.

Erosion, soil. Removal of soil material from the solum by wind or running water, including normal soil erosion and accelerated soil erosion.

Erosion, normal soil. The erosion characteristics of the soil type under the native vegetation, undisturbed by human activity.

Erosion, accelerated soil. Erosion of the soil over and above the normal erosion, brought about by changes in the natural cover or ground conditions.

Family, soil. A category in the system of soil classification be-

tween soil series and great soil group; a taxonomic group of soils having similar profiles, composed of one or more distinct soil series.

Fertility, soil. The quality that enables a soil to provide the proper chemical compounds, in the proper amounts and in the proper balance, for the growth of specified plants, when factors such as light, temperature, and the physical condition of the soil are favorable.

Flocculate. To bring together into small groups, clumps, or granules, individual particles, especially of clay and soil colloids.

Friable. Easily crumbled in the fingers.

Glei horizon. A soil horizon in which the material is bluish-gray or olive-gray, more or less sticky, compact, and often without structure, developed under the influence of poor drainage, especially if there is abundant organic matter in an adjacent horizon.

Gleization. A general term for the process of soil formation leading to the development, under the influence of poor drainage, of a glei horizon in the lower part of the solum.

Great soil group. A broad group of soils with fundamental internal characteristics in common. Some of these groups are Chernozem, Gray-Brown Podzolic, Solonetz, Brown, Podzol, et cetera. Those that are zonal are sometimes called the *continental soil types.*

Green manure crop. Any crop grown and plowed under for the purpose of improving the soil, especially by the addition of organic matter.

Gully. A channel produced by erosion, especially accelerated soil erosion, too deep to be obliterated by normal tillage. These erosion-produced channels ordinarily carry water only during or immediately after rains, or following the melting of snow.

Hardpan. A hardened or cemented soil horizon beneath the surface.

Horizon, soil. A layer of soil approximately parallel to the land surface, except for tongues or minor irregularities, with more or less distinctive soil characteristics that have been produced through processes of soil formation. (See Figure 12 for illustration showing the relative position of the several horizons within a soil profile).

Humid climate. Generally, a climate with sufficient rainfall to support a forest vegetation, although there are exceptions.

The term "humid" is also applied to an atmosphere with a high average relative humidity.

Humus. The well-decomposed, more or less stable portion of the organic matter in soils.

Igneous rock. A rock produced by the cooling of melted mineral material.

Immature soil. A young or imperfectly developed soil that has not yet come into equilibrium with its environment.

Inherited characteristic (of soil). Any characteristic of a soil that is due directly to the nature of the parent material in contrast to those wholly or partly due to processes of soil formation. For example, a Podzol may have a pinkish or reddish tinge entirely because the parent material is red.

Intrazonal soil. Any of the great groups of soil with more or less well-developed characteristics that reflect the influence of some local factor of relief or parent material, or both, over the normal effect of climate and vegetation. Each intrazonal soil, such as Ground-Water Podzol, Bog, Solonetz, or Rendzina, may be found associated with two or more groups of zonal soils.

Land. The total natural and cultural environment within which production must take place.

Landscape. The total characteristics that distinguish one certain area on the earth's surface from other areas. These include such natural features as soil, vegetation, rock formations, hills, valleys, and streams, as well as such cultural features as cultivated fields, roads, and buildings. The term *natural landscape* refers to one without cultural features.

Lateritic soil. A soil having all or part of the characteristics of a Laterite. One especially in which there has been an accumulation of iron oxide and alumina through intense weathering of the minerals.

Laterization. The general process that is responsible for the formation of Laterites or lateritic soil materials.

Leaching. The removal of soluble materials in solution.

Lime. Strictly, calcium oxide (CaO), but commonly used to include calcium carbonate ($CaCO_3$) and calcium hydroxide ($Ca(OH)_2$). The term *agricultural lime* is applied to any of these compounds, with or without mixtures of magnesia (MgO), used as an amendment on acid soils.

Marl. An earthly crumbling deposit consisting chiefly of calcium carbonate mixed with clay or other impurities.

Mature soil. A soil with well-developed soil characteristics pro-

duced by the natural processes of soil formation, and in equilibrium with its environment.

Mediterranean climate. A general term used in reference to warm-temperate climates, relatively dry in the warm season and relatively moist in the cool season, like that of the southern coast of France.

Microrelief. Minor surface configurations, such as low mounds or shallow pits, considered collectively.

Morphology, soil. The physical constitution of the soil, including texture, structure, porosity, consistence, and color of the various soil horizons, their thickness, and their arrangement in the soil profile.

Muck. Fairly well or well-decomposed organic soil material, relatively high in mineral matter, dark in color, and accumulated or produced under conditions of poor drainage.

Mull. A type of organic surface horizon of forested soils in which the organic matter is well-decomposed and largely humus, granular in structure, relatively rich in bases, and usually medium acid to slightly alkaline in reaction, and more or less mixed with mineral matter in the lower part.

Nitrification (in soils). The formation of nitrates (compounds containing a NO_3-group, like KNO_3, potassium nitrate) from ammonium salts (compounds containing a NH_4-group, like NH_4Cl, ammonium chloride) by micro-organisms.

Nitrogen fixation in soils. The assimilation of nitrogen from the air by micro-organisms, thus eventually making this nitrogen available to plants in forms they can use. Nitrogen-fixing organisms associated with legumes, like alfalfa and the clovers, are called *symbiotic;* while those growing independently of plants are called *non-symbiotic.*

Normal soil. A soil having a profile in equilibrium with the native vegetation and climate, and usually developed on the gently sloping or gently rolling upland, with good drainage, from any kind of parent material, not of extreme texture or chemical composition, that has been in place long enough for the biological processes to have had their full effect.

Ortstein. Hard, unequally cemented, dark-yellow to nearly black sandy material formed in the lower part of the solum. This material frequently makes up the B_2 horizon of Ground-Water Podzols and sandy Podzols. Similar material not firmly cemented is called *orterde.*

Parent material. The unconsolidated mass from which the soil profile develops.

Parent rock. The rock from which parent materials of soils are formed.

Peat. Unconsolidated soil material consisting largely of undecomposed or slightly decomposed organic matter and low in mineral matter, accumulated under conditions of excessive moisture.

Pedalfer. A term introduced by Dr. Marbut for a soil in which there has been a shifting of alumina and iron oxide downward in the soil profile but with no horizon of carbonate accumulation. Roughly equivalent to "soils of the humid regions." Derived from terms meaning soil, aluminum, and iron.

Pedocal. A term introduced by Dr. Marbut for a soil with a horizon of accumulated carbonates, the lime zone, in the lower part of the solum or just beneath it. Roughly equivalent to "soils of the arid and semiarid regions." Derived from terms meaning soil and calcium.

Pedogenic processes. Processes of soil formation.

Pedologic (pedological). Pertaining to pedology or soil science.

Pedologist. One versed in pedology; a soil scientist.

Pedology. The science that treats of soil; soil science. Pedo is from the Greek for ground or earth. The term is used commonly for the more fundamental aspects of soil science, whereas the term agrology is used sometimes for the applied phases of the subject. In the United States, the term "agronomy" is used frequently to cover the applied phases of both soil science and the several plant sciences dealing with crops. This use of agronomy is so broad as to be somewhat confusing, however, and more and more this term is being confined to the applied phases of the plant sciences dealing with crops. The term "edaphology" has been used by some as an approximate equivalent to soil science and by others to cover plant-soil relationships. Although it is not widely used, one of its derivatives, edaphic, is used by ecologists as a general term for soil influences or conditions.

pH. A notation used to indicate weak acidity or alkalinity, as in soils. (Technically it is the common logarithm of the reciprocal of the hydrogen-ion concentration in gram-mols per litre). A pH of 7.0 indicates precise neutrality, higher values indicate alkalinity, and lower values acidity. (See Reaction, soil).

Phase, of soil type. The lowest unit in soil classification that in-

cludes those soils within a soil type having external characteristics, such as relief, stoniness, or accelerated erosion that vary from those normal for the type to a degree significant to the use of the land; but with profiles essentially like those of the normal soil type.

Plant food. The organic substances, made within the plant, which nourish its cells. (Sometimes used loosely in place of plant nutrient).

Plant nutrients. The elements taken in by plants, essential to their growth, and used by them in the manufacture of food and tissue. These include nitrogen, phosphorus, calcium, potassium, magnesium, sulphur, iron, manganese, copper, boron, zinc, and perhaps others obtained from the soil, and carbon, hydrogen, and oxygen, obtained largely from the air and water.

Podzolic soil. Soils formed partly or wholly under the influence of podzolization.

Podzolization. A general term referring to the process (or processes) by which soils are depleted of bases, become acid, and have developed surface (A) horizons of removal and lower (B) horizons of accumulation of colloids and iron and aluminum compounds. This process is best expressed in the Podzol soils, but also influences many of the other soils developed under forests in humid regions.

Productivity (of soil). The capability of a soil for producing a specified plant or sequence of plants under a physically defined system of management.

Profile, soil. A vertical section of a soil through all its horizons and extending into the parent material.

Reaction, soil. The degree of acidity or alkalinity of a mass of soil. In practice, the words used and the approximate ranges in pH values are as follows:

	pH		*pH*
Extremely acid	Below 4.5	Neutral [2]	6.6–7.3
Very strongly acid	4.5–5.0	Mildly alkaline	7.4–8.0
Strongly acid	5.1–5.5	Strongly alkaline	8.1–9.0
Medium acid	5.6–6.0	Very strongly alkaline	9.1 and higher
Slightly acid	6.1–6.5		

[2] Strict neutrality is precisely pH 7.0. Very few actual soil samples have this value and those having pH values between 6.6 and 7.3 are considered, for all practical purposes, neutral. For more precise identification, those between 6.6 and 7.0 are described as very slightly acid, and those between 7.0 and 7.3 as very mildly alkaline.

Reclamation (*of land*). Making land capable of more intensive use by changing its character, environment, or both, through operations requiring collective effort, such as large irrigation and drainage works. Fertilization, liming, clearing of stumps, brush, and stones from land, and simple water and erosion control practices that can be done by the individual, are not included within reclamation.

Residual (*or sedentary*) *material.* Soil material presumably developed from the same kind of rock as that upon which it lies. (The term "residual" is sometimes incorrectly applied to soil developed from such materials).

Rills. Small channels caused by soil erosion that are obliterated by tillage in fields, or by natural filling in the natural landscape.

Saline soil. A soil containing an excess of soluble salts, more than about 0.2 percent, and not very highly alkaline. Sometimes they are called salty soils, and in the scheme of soil classification most of them are Solonchak soils.

Sand. Small rock or mineral fragments having diameters ranging from 1 to 0.05 mm.; coarse sand, 1 to 0.5; medium sand, 0.5 to 0.25; fine sand, 0.25 to 0.1; very fine sand, 0.1 to 0.05. The term "sand" is also applied to soils containing 90 percent or more of all grades of sand combined. Although usually made up chiefly of quartz, sands may be composed of any materials or mixtures of mineral or rock fragments.

Sedimentary rock. A rock composed of particles, more or less cemented together, deposited from suspension in water. The chief ones are (1) *conglomerates* (from gravel); (2) *sandstones* (from sands); (3) *shales* (from clays); and (4) *limestones* (from calcium carbonate deposits); but there are many intermediate types.

Semiarid climate. Generally, a climate intermediate between the desert and subhumid, with sufficient rainfall to support a native vegetation of short grasses, bunch grasses, or shrubs.

Series, Soil. A group of soils having similar profiles, except for the texture of the surface soil, and developed from a particular type of parent material. A series may include two or more soil types differing from one another in the texture of the surface soils.

Sheet erosion. The removal of a more or less uniform layer of material from the land surface by erosion, although at any one

time the eroding surface usually consists of numerous unstable or temporary small rills.

Silt. Small mineral soil particles that range in diameter from 0.002 mm. to .05 mm. (Formerly 0.005 mm. to 0.05 mm.).

Skeletal Soils. Equivalent to Lithosols.

Soil. The natural medium for the growth of land plants on the surface of the earth. A natural body on the surface of the earth in which plants grow, composed of organic and mineral materials.

Soil climate. Moisture and temperature conditions within the soil.

Soil map. A representation designed to portray the distribution of soil types, phases, and complexes, as well as other selected cultural and physical features of the earth's surface necessary for convenience in its use.

Detailed. The boundaries of soil types and phases are plotted upon the base map from precisely located points and from observations made throughout their course in sufficient detail to indicate those differences of significance in the use of the land.

Reconnaissance. The boundaries between the soil types and phases are plotted from observations made at intervals.

Detailed-reconnaissance. A map having parts constructed according to the requirements of the detailed soil map and parts according to the less rigid requirements of the reconnaissance soil map.

Solodized soil. A soil that has been subjected to the processes responsible for the development of a Soloth and having at least some of the characteristics of a Soloth.

Solum. The upper part of the soil profile, above the parent material, in which the processes of soil formation are taking place. In mature soils this includes the A and B horizons, and the character of the material may be, and usually is, greatly unlike that of the parent material beneath. Living roots and life processes are largely confined to the solum.

Stratified. Composed of, or arranged in, strata or layers, as stratified alluvium. The term is applied to geological materials. Those layers in soils that are produced by the processes of soil formation are called horizons, while those inherited from the parent material are called strata.

Strip cropping. Strip cropping is a practice of growing ordinary farm crops in long strips of variable widths, across the line of

slope, approximately on the contour, on which dense-growing crops are seeded in alternate strips with clean-tilled crops.

Structure, soil. The morphological aggregates in which the individual soil particles are arranged. The following are the principal types of soil structure:

Platy: The soil grains are arranged in horizontal plates.

Prismatic: The soil grains are arranged in vertical, elongated prisms, roughly six-sided. *Columnar:* A variety of prismatic, in which the tops of the prisms are rounded.

Blocky: Irregular blocks of soil particles, large or small. When the angles are rounded the structure is frequently called *nut-like.*

Granular: Firm rounded aggregates, usually small. *Crumb:* A variety of granular, with irregular shape and highly porous.

A lack of structure is indicated as:

Massive: Large irregular masses of cohesive soil, sometimes with irregular cleavage to produce large clods.

Single grain: Each soil grain by itself, as in dune sand.

Subhumid climate: A climate intermediate between semiarid and humid, with sufficient rainfall to support a moderate to dense growth of tall and short grasses.

Subsoil. Roughly, that part of the solum, or true soil, below plow depth.

Surface soil. The upper part of cultivated soils commonly stirred by the plow or other tillage implements (or an equivalent depth (5 to 8 inches) in nonarable soils).

Terrace. (For control of run-off, or soil erosion, or both). A broad surface channel or embankment constructed across the sloping lands, on, or approximately on contour lines, at specific intervals. The terrace intercepts surplus run-off, to retard it for infiltration or to direct the flow to an outlet at nonerosive velocity. A bench terrace is approximately on the contour, having a steep or vertical drop to the slope below, and having a level or gentle sloping part which is farmed. It is adapted to the steeper slopes.

Texture, soil. The relative proportion of the various size groups of individual soil grains.

Soil separates. The individual size groups of soil particles, such as sand, silt, and clay.

Soil class. Classes of soil based on the relative proportion of soil separates. The principal classes, in increasing order of

the content of the finer separates, are as follows: Sand, loamy sand, sandy loam, loam, silt loam, clay loam, and clay. These may be modified according to the relative size of the coarser particles to fine sand, loamy fine sand, fine sandy loam, very fine sandy loam, coarse sandy loam, gravelly sandy loam, gravelly loam, cobbly loam, sandy clay, stony clay, silty clay, stony loam, etc.

Tilth. The physical condition of a soil in respect to its fitness for the growth of a specified plant, or sequence of plants.

Topsoil. A general term sometimes applied to the surface portion of the soil, including the average plow depth (surface soil) or the A horizon, where this is deeper than plow depth. The term is very vague and can only be precisely defined as to depth or productivity in reference to a particular soil type.

Transported soil material. Parent materials of soils that have been moved from the place of their origin and redeposited during the weathering process itself or during some phase of that process, and which consist of, or are weathered from, unconsolidated formations. Sometimes used incorrectly in reference to soils.

Truncated soil profile. A soil profile that has had a part of the solum removed.

Type, soil. A group of soils having genetic horizons similar as to important characteristics, including texture and arrangement in the soil profile, and developed from a particular type of parent material.

Varnish, desert. A glossy coating of dark-colored compounds, probably composed largely of iron oxides, covering pebbles, stones, and large rock surfaces exposed in hot deserts.

Vertical zonality of soils. The distribution of different great soil groups on mountain slopes, each group occupying a definite climatic and vegetative zone.

Water table. The upper limit of that part of the soil or underlying material wholly saturated with water.

Weathering. The physical and chemical disintegration and decomposition of rocks and minerals.

Wet climate. A climate with enough moisture to maintain a rainforest.

Wet-dry climate. A climate with alternating wet and dry seasons.

Zonal soil. Any one of the great soil groups having well-developed soil characteristics that reflect the dominating influence of vegetation and climate.

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[1] The glossary is not included in the index and may be consulted for definitions, except for the great soil groups defined in Appendix II, pages 330 to 340.